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ABSTRACT

This report enumerates the activities of the Educational Technology Center (ETC) during 1987. The guide's theme for the year was Teaching with Technology. The report includes brief descriptions of five different types of research projects by area. In science education, the projects concerned with weight and density, heat and temperature, and the nature of science. Projects in mathematics education included those related to geometry, word problems, and algebra. The research in computing education centered on programming and systems thinking. Research in new technologies centered on computer-based conferencing and videodiscs. And the fifth project area, research in laboratory sites, explored what it takes to carry out ETC-developed innovations in regular schools. Other center activities included agenda building and review, dissemination of the results of center work, and training activities. (PK)

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INTRODUCTION

The guiding theme for ETC's work during this, its fourth, year has been Teaching with Technology. At first blush such a phrase sounds self-evident -- if not redundant -- for an organization called the Educational Technology Center. Yet ETC proceeded from day one on the premise that before launching into the development and study of technologically sophisticated methods of teaching, researchers must carefully identify the educational problems they hope to solve and analyze the fit between those problems and the potential of information technologies.

An equally important early premise was that "researchers" must include not only university-based experts, who traditionally have studied learning and schooling, but also subject matter specialists, technology experts, and practicing teachers who can help to ensure that the results of research are theoretically sound and practically applicable in classrooms. Thus, from the beginning ETC convened research groups that brought together members of diverse constituencies and supported them in the sometimes difficult process of collaboration.

The first task of these groups was to identify targets of difficulty, ETC's way of conceptualizing and describing research topics that are both central to their disciplines and troublesome for teachers and students. Having chosen these topics, the groups began a careful analysis of subject matter, of students' difficulties in learning it, and of the advantages technology might offer in easing those difficulties. What was learned in those areas became the educational basis to support and inform the testing and refinement of technology-enhanced methods of teaching and learning.

SUBJECT MATTER AND STUDENTS' CONCEPTIONS OF IT

Most ETC research groups started with an assumption supported by prior research: that students' intuitive ideas about scientific and mathematical phenomena often interfered with learning the concepts and models presented by teachers and textbooks. In many cases, the research groups' early studies added depth and nuance to what was already known of students' prior notions about such targets of difficulty as density, heat, and intensive quantities. With these carefully drawn maps of students' cognitive frameworks, researchers were able to think systematically and insightfully about the teaching materials and strategies that might assist students in making the needed conceptual changes in their intuitive theories.

TEACHING FOR CONCEPTUAL UNDERSTANDING

In devising teaching methods, most group's were guided by another principle that has characterized ETC's approach from the beginning: that effective pedagogical methods combine features of both structured, teacher- or computer-directed instruction and free exploration by students. The former makes use of the teacher's greater knowledge and experience and insures that elements essential to the discipline and to a particular curriculum will be covered; the latter provides students with the all-too-rare school experience of formulating and solving problems, working collaboratively with each other, and actively constructing understanding. This blend is a feature of virtually every project's work, though the balance of guidance and inquiry varies, as does the extent of reliance on technology versus traditional teaching materials.

One additional and rather uncommon dimension of ETC's work is its emphasis on the nature of knowledge, evidence, and inquiry within disciplines. Stemming from the priority given to thorough analysis of subject matter, this dimension has meant that ETC teaching approaches seek, for example, not only to build students' understanding of particular geometric laws and properties, but also to establish an understanding of what it means to make, test, and prove geometric hypotheses; not only to teach students to articulate definitions and solve problems involving concepts of weight and density, but also to help them understand how and why people construct models of scientific phenomena such as density.

THE ROLE OF TECHNOLOGY

Once basic questions about conceptual domains and teaching approaches had been answered, research groups turned to an examination of how technology could enhance their pedagogical aims. Across projects and subject matters, Year Four has seen the exploration and exploitation of three particular technological capabilities. First, ETC teaching approaches have taken advantage of the computer's capability for graphic display of models and representations. In science, for example, researchers have used this ability to present students with interactive computer-based models of the relationships of size, weight, and density and of the kinetic behavior of molecules during heating, cooling, and thermal equilibrium. In mathematics, computer capability has allowed researchers to link multiple representations of intensive quantities -- from basic iconic representations of quantities such as three trees per yard to tables of data, coordinate graphs, and algebraic equations -- forming a "learning ramp" to help move students from the concrete acts of matching, grouping, and counting to mastery of more abstract and mathematically more powerful representations.

ETC teaching approaches have also taken advantage of the computer's capacity to extend the range of manipulable objects beyond the tangible forms of Cuisenaire rods, blocks, and objects examined under a microscope. With technology, it becomes not only possible but easy for students to make screen

"objects," such as constructions of geometric figures which they can then measure, alter, enlarge, and repeat on the computer. In science, students are no longer limited to experience with real-world materials which force them to infer an object's density from its weight and size. The computer enables them to choose materials of different kinds and build screen objects of varying sizes in which density is depicted in a visual dots-and-grid display.

Finally, ETC teachers and researchers have found that the computer provides a valuable window on their students' thinking and learning. Teachers inexperienced with technology often worry that the machine will come between them and their students. While this may happen with some drill-and-practice programs or extremely discovery-oriented uses of computers, ETC's approach to using technology enhances teachers' role in guiding their students' learning and makes them co-creators of knowledge. In classrooms where this approach is used, teachers not only present whole-class explanations and demonstrations, but they also consult with students working independently, pose and solve problems with them, and observe their behavior as they work through problems using a combination of computer-based and traditional materials. Far from separated from their students, these teachers have a much closer and more vivid view of the active learning process.

MOVING FURTHER INTO THE CLASSROOM

Another salient feature of ETC's work in Year Four has been the emphasis on classroom-based research. As the testing and refinement of teaching materials has progressed, research groups have worked closer to the heart of regular classroom practice. Many projects moved from clinical studies with small numbers of students to whole-class studies which tested both the educational effectiveness of their materials and their "teachability." These studies provided valuable feedback on both counts and enabled the groups to revise and refine the materials appropriately for future phases of testing. Reaching this phase of research has been particularly satisfying given the Center's commitment to the improvement of classroom practice.

In addition to each project's testing of the effectiveness of its prototype teaching materials, ETC wanted to learn more about the process by which individual teachers and schools as organizations implement educational innovations. In the fall of 1986 the Center established laboratory sites in five Massachusetts high schools to study the implementation of research-based innovations in classrooms. Three projects -- Heat/Temperature, Geometry, and Programming -- whose innovations were most fleshed out and ready for trial in large numbers of classrooms, were selected for use in the laboratory sites. Experience in these classrooms has provided insight into two sets of implementation requirements: the logistical and technical conditions that must be met before effective teaching is possible and the supports and resources that help teachers integrate a new technology into their curriculum and customary teaching style.

RESEARCH PROJECTS

RESEARCH IN SCIENCE EDUCATION

Area Coordinator: Susan Carey, Massachusetts Institute of Technology

ETC's research projects in science education have worked to help students learn difficult conceptual distinctions that form the foundation for further learning in science. In Year Four, the Weight/Density Project continued to focus on elementary and junior high school students' differentiation of weight from density, which builds the basis for understanding the structure of matter. The Heat/Temperature Project has concentrated on high school students' differentiation of heat from temperature, the basis for understanding energy transfer in biological, chemical, and physical sciences. Both groups developed instructional materials and strategies and tested them in classrooms.

In addition, the science groups have been concerned with teaching students about the construction of scientific knowledge -- the *how* and *why* of scientific work. The Nature of Science Project has specifically examined elementary and junior high school students' understanding of the nature of science and scientific inquiry. Within the teaching unit this project developed, and throughout ETC's science education materials, this emphasis has meant not only teaching students methods of controlled experimentation but also discussing with them the purpose and development of scientific models.

Weight and Density

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The concept of density (the first intensive physical quantity students encounter that can be understood in terms of an underlying model of matter) is commonly introduced in the junior high school science curriculum. The traditional way the topic is introduced, however, is formal and empirical. Students are given a mathematical formula relating mass and volume and are taught specific procedures for measuring the densities of solids and liquids. They are not encouraged to think intuitively or theoretically about the natures of the underlying quantities or to develop models that show their interrelations.

although modeling is a technique scientists often use in constructing their own understanding.

Teachers consistently report that students have great difficulty understanding the concept of density as well as related phenomena (water displacement, sinking and floating, thermal expansion). One common explanation is that junior high school students are not yet capable of the formal operational thought that these topics require. Research by Smith and her colleagues, however, has shown that age is not the critical barrier to students' understanding. A more satisfactory explanation is that students come to science class with conceptual frameworks in which the concepts of weight and density are not yet differentiated. Developing a concept of density thus requires that students make a fundamental conceptual change. Traditional science instruction, geared to memorization of formulas and definitions, encourages rote learning and makes it hard for students to think about their own ideas. The Weight/Density Group advocated an alternative approach to instruction, one which encourages students to model their ideas (as they explore phenomena that require a distinction between weight and density) and to work with computer-based models developed at ETC. In the fourth year, the group's work centered on developing an extensive classroom-based teaching intervention to promote conceptual change and testing its effectiveness.

From analysis of students's intuitive conceptions as well as of experts' scientific theories, the group identified a range of activities to help students revise their conceptual frameworks. These activities compose a curriculum unit designed to encourage students (1) to analyze the weight of objects in terms of a theory of matter and to have them see the need for articulating weight and density as two distinct concepts; (2) to use their qualitative understanding of density in formulating a predictive rule for sinking and floating; (3) to advance from seeing density as an invariant characteristic of material kinds defined solely by comparative procedural tasks to understanding a mathematical formulation in which density is seen abstractly in terms of weight/size relationships; and (4) to use this mathematical formulation to understand the phenomenon of thermal expansion.

The project's approach differs from other attempts to teach these concepts both by working with a younger group (sixth- and seventh- rather than ninth-grade students) and by building on students' conceptions of material kind. Instead of beginning with a formal mathematical definition of density, students are encouraged to build paper-and-pencil models in which they represent weight and density in different ways. Next, they are presented with computer models. The premise is that modeling, which allows students to "see" their ideas, also directs their thinking toward theory (underlying conceptual relationships) and provides an opportunity to teach them about the nature of science, in particular an understanding of models and how they help scientists understand phenomena. The advantages of computer-based, rather than hand-drawn, models are that students can interact with them to see the consequences of the representations,

discover the rules embodied in them, and begin to link multiple representations of the same situation.

Thus, the main study implemented in Year Four was a longitudinal classroom study of students' learning through three teaching units about weight and density. The purpose was to assess the effects of sustained inquiry using a combination of computer models and hands-on activities. In addition, a study of teaching strategies was designed and executed, whose purpose was to test both specific hypotheses about the role of the computer simulation in bringing about conceptual change and the effects of different sequences of instruction on students' understanding.

The Longitudinal Study of Student Learning

This study was conducted with students in one sixth-grade and one seventh-grade class, both in suburban schools. Students in the sixth-grade class (11 girls, 9 boys) had heterogeneous math abilities, while those in the seventh-grade class (11 boys, 6 girls) had high math ability.

Designed to promote understanding of the distinctness as well as the interrelatedness of the concepts of weight and density, the intervention linked these concepts to specific real-world phenomena and, through computer-based models, emphasized the relation of density to weight and volume. Three units were developed; the first (ten lessons) concerned differentiation of weight and density in relation to sinking/floating phenomena, the second (six lessons) applied this concept in the context of thermal expansion, and the third (four lessons) looked at objects made of a mixture of materials to introduce students to the idea of average density.

Three principles governed development of the curriculum: (1) build on students' preconceptions; (2) move students from a qualitative understanding of a particular phenomenon to a more quantitative understanding; and (3) use models to develop their understanding, discussing with them the process of modeling as part of scientific work. In addition to computer models, students worked with a variety of hands-on activities and saw a variety of demonstrations (e.g., changes in the density of water with heating, an object that floats in cold water but sinks in warm). They were asked to explore, discover regularities in, and model situations using objects of varying materials (steel, wood, brass, or aluminum) and sizes, vessels filled with oil, water, or clay.

Assessment

Students' understanding of the distinction between weight and density was probed using both clinical interviews (administered to a large sample of each class) and written tests (administered to all students). The interviews and tests were given at three points: prior to unit 1, after unit 1, and after unit 2. (A different test was given before and after unit 3.)

The clinical interview involved ordering objects by weight and density, inventing models to represent both dimensions visually, organizing an understanding of sinking/floating phenomena, and answering questions on how adding material and thermal expansion affect weight and density. It did not require initial knowledge of the word "density," and only questions on thermal expansion required students to abstract the notion of density from material kind.

The written test, which preceded the interview, did not require students to order objects but to predict relative weights of pictured object pairs and whether two objects could be made of the same material. Two tasks included in the written test but not in the interview required students to define the word density and compute the density of objects from their volume and weight. As in the interview, they were questioned about what happens to the density of material when more is added or a fixed amount expands with heating.

In each of the five tasks used in the interview, three levels of understanding of density were distinguished: (1) making no distinction between weight and density, (2) making a beginning but uncertain distinction, and (3) making a clear distinction. Responses were coded by two scorers and disagreements resolved through discussion. Students' responses across the tasks were highly correlated, with consistent difficulties associated with particular tasks; modeling was more difficult than ordering, and the thermal expansion task most difficult of all.

Students' patterns of response over the whole interview were classified in terms of three basic levels (absence of a concept of density, lack of weight/density differentiation, and weight and density differentiation). The last two levels were further divided into two sublevels.

Students at Level 1 (density absent; absolute weight) made no distinction between weight and density on any task; they used a notion of absolute weight, without that of "heavy for size." Such students went on to become confused by sinking/floating and thermal expansion phenomena.

Students at Level 2a (strong weight/density; lack of differentiation) were beginning to demonstrate an initial fragile understanding by making some distinctions in the ordering tasks. Rather than order objects strictly by density, however, they vacillated among criteria (heaviness, "heavy for size," kind of material) and when asked to model the weight and density of objects were able to represent only one dimension -- absolute weight, a combined density/weight concept, or density alone. Students at Level 2b (transitional weight/density; lack of differentiation), although still not clearly differentiating weight and density into distinct dimensions, showed greater awareness of two dimensions in their models and generally revealed more sophisticated thinking.

Students at Level 3a (density/material kind) could distinguish clearly between weight and density where density covaried with material kind (ordering, modeling, sinking/floating, adding material tasks) but did not understand what happens to weight and density in thermal expansion. Perfect in performing ordering tasks (pairwise comparisons and four-object ordering), they typically

represented two dimensions in their models, knew that adding material increases the weight but not the density of an object, could use a notion of density to organize their understanding of sinking and floating, but were still quite confused about thermal expansion. On the pretest on thermal expansion, they either made no distinction between weight and density or, more typically, made an incorrect one. At Level 3b (density), students not only distinguished between weight and density when density covaries with material kind but also maintained their understanding of the distinction in thinking about thermal expansion. In the pretest a few who showed this pattern could represent weight and density as distinct dimensions in their models but could not capture the interrelation; by the posttest all but one had assimilated the grid-and-dots model and were capable of representing the relation and distinctness of size, weight, and density.

Comparison of interview and test responses showed that the written test detects the kinds of patterns uncovered in the interview but tends to overestimate student understanding. Nevertheless, the written test provided information not gained by the interview in three important areas. First, it showed that even before being able to differentiate the two dimensions clearly, students began to think quantitatively about density, suggesting that quantitative thinking may be important in consolidating the differentiation. Second, although students might have heard of the word "density," they thought of it incorrectly as an extensive quantity, that is, as corresponding to an object's weight or size. Third, most students, even those with a grasp of the distinction between weight and density, did not have a good understanding of sinking/floating without experience with the phenomena.

Findings

Many students progressed in their understanding of density, as assessed by the written test and clinical interview. Students who received clinical interviews moved from 37% showing a clear ability to differentiate between weight and density to 66% at the time of posttest 1 and 70% at the time of posttest 2.

On the written test, gains differed by task and also between students who were or were not interviewed. Of students interviewed, on the galt and lidium task correct quantitative understanding of density increased from 27% (pretest) to 40% (posttest 1) and 53% (posttest 2); on sink/float questions and verbal tasks, understanding increased from about 15% to about 60% on posttests. Of students not interviewed, correct quantitative understanding increased from 20% to 40% of students; on the sink/float tasks understanding increased from 20 to 67% and 40%. However, performance was more uneven on the verbal tasks.

Overall, the study suggests that the teaching intervention was successful in bringing about two kinds of change: (1) conceptual differentiation, in students who did not initially differentiate between weight and density and were led to do so; and (2) conceptual consolidation, in students who had already made a basic distinction between weight and density and now deepened their understanding of

it. The two factors that seemed to have the greatest impact on students' progress were their starting level of understanding and their participation in the clinical interviews. Students who had only the written test were slower to change than those interviewed, made less radical conceptual changes, and were more uneven in their final performance. The intervention was most effective for the majority who were initially at Level 2b and thus were already on the verge of differentiation. Generally, students who already had a concept of density were prepared to learn a verbal label for it, to learn appropriate quantification, and to learn about sinking/floating and thermal expansion. After the teaching they were more consistent in their performance across tasks. Again, the clinical interview may have played a part in promoting conceptual change, perhaps helping students to become conscious of the tensions (puzzles) implicit in their conceptualizations. Students with lower initial levels made some progress as a result of the teaching but may have needed a more radical change in framework.

Although this study was not designed to test systematically the instructional value of clinical interviews, the results suggest that engaging students' initial conceptions through such interviews and using modeling activities are both important teaching tools. Researchers at ETC are now exploring how teaching situations might be structured to make them more responsive to individual needs and differences and to learn what students understood about the modeling process. Improvements in the written test are also planned to improve its sensitivity and to make it more comparable to the clinical interview. More items should be incorporated into the written test that do not presuppose an understanding of the word "density," and more sinking/floating demonstrations should be included so that prior knowledge of the phenomena is not required.

The Teaching Strategies Study

Based on analysis of the pilot study conducted in the spring of 1986, this study was designed to test two hypotheses, one about the role of the computer simulation in students' learning and one about the influence of teaching sequences. The first hypothesis was that students who work with a computer simulation (as well as real materials) will more fully integrate a flotation rule using density than will student who use only real-world materials. The second hypothesis is that students who do experiments to disconfirm a weight rule for flotation after they have been introduced to the distinction between weight and density will more fully understand the counterexamples and reject a weight-based rule than will those who do such experiments before density instruction.

One hundred sixth and seventh graders participated in this study. On the basis of an initial quick scoring of their pretest, they were randomly assigned to one of four treatment groups -- (1) density instruction *before* flotation; flotation instruction with real materials alone; (2) density instruction *before* flotation; flotation instruction with real materials and the computer simulation; (3) density instruction *after* flotation; flotation instruction with real materials

alone; (4) density instruction *after* flotation; flotation instruction with real materials and the computer simulation. Posttests were administered immediately after the intervention and again approximately three weeks later. The results of this study were still being analyzed at the conclusion of Year Four.

Heat and Temperature

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The target of difficulty for the Heat and Temperature Group is basic thermal physics, and their research has focused on problems students have making the differentiation between heat and temperature necessary for an understanding of most thermal variables, laws, and principles. The three interrelated goals of the project are: to characterize the ideas and concepts students develop on their own and bring into the classroom; to develop a microcomputer-based curriculum that addresses students' preconceptions; and to monitor the interaction between students and curriculum. A fourth goal has been to develop methods to assess the effects of the teaching intervention.

Previous Work

Earlier research led the group to define students' alternative frameworks in basic thermal physics as an entrenched, well-integrated network of ideas that allow them to make sense of everyday phenomena but prevent them from assimilating textbook theory without a complete conceptual reorganization, which typically fails to occur. Researchers found that students attempt to integrate information presented in class into their framework, distorting it to fit, sometimes severely enough to lead to additional misconceptions or, when the information is simply incompatible with their framework, ignoring it.

The group's initial teaching interventions used microcomputers as laboratory tools: Microcomputer-Based Laboratories (MBL) allow students to collect, display, and summarize data; Laboratory Simulations allow them to "conduct" on the screen experiments impractical to carry out in the real classroom laboratory. The content of the interventions was chosen to challenge students' preconceptions. Classroom trials of these computer-based interventions revealed that the computer teaching helped students learn to solve quantitative problems about mass, heat, and temperature as well as to understand phase change. The lessons did not, however, facilitate the conceptual reorganization required to understand heat as the mechanical energy transferred

from a hotter body to a colder one or that it is measured by its amount, not by its temperature.

Concluding that students need not only empirical evidence that contradicts their beliefs but a theoretical alternative they can understand in spite of them, researchers began work on a series of kinetic molecular models that present thermal phenomena visually and address the framework of misconceptions students bring to the classroom.

The Need for Molecular Models

The results of the previous classroom studies indicated that for textbook theory to be assimilated it must be made explicit at the micro-level, and here computer models may provide a solution. To differentiate between heat and temperature students need visual kinetic models, for several reasons: (1) The key concept they lack and have difficulty acquiring is amount of heat, an extensive variable visual models are particularly suited to represent. (2) With kinetic molecular models, which make use of their mechanical intuitions, dealing with motions and collisions, students can exploit a rich store of preexisting knowledge that will give meaning to textbook theory and consequently help them give up their own frameworks. (3) Molecular models provide an explanatory mechanism for laws and principles students need to learn, giving these a necessity lacking at the macroscopic level. (4) As shown from the group's previous research, the (few) students who learn to differentiate between heat and temperature within the terms of a traditional curriculum already have a molecular model for thermal phenomena.

Although most textbooks for ninth-grade science curricula include the molecular basis of thermal physics, they do not systematically exploit the molecular model. As traditionally taught, the model accounts very well for thermal dilation -- and students find it compelling and easy to assimilate -- but does little to dispel their misconceptions or help them understand the nature and extensivity of heat or the meaning of thermal laws. Existing visual models (films, software) are similarly flawed: they show molecules moving faster at higher temperatures and the distance between them increasing, but they do not address fundamental conceptual difficulties.

The models devised by the group emphasize the amount of (disorganized) mechanical energy in one molecule and in a whole object. Amount of energy is represented by a discrete number of energy dots. Although molecular motion is illustrated in the model and shown to be correlated with amount of energy dots per molecule, it is not the central feature of the models. Rather than simply illustrate definitions at the molecular level, the models explicate in molecular terms the relations of heat, mass, and temperature, making the extensivity of heat evident. Since the models apply also to phenomena of specific heat, they incorporate all the phenomena and laws students require for a basic understanding of thermal physics, with the exception of changes of state, which

will be addressed in the future. Last, through use of the models, students also learn to solve problems.

The Computer Models

The three initial models were CONTAINERS, COLLISION, and KINETIC & INTERNAL ENERGIES.

CONTAINERS, the main model, introduces the concepts of heat and temperature, the quantitative relation of heat, mass, and temperature, molecular motion, and conduction. Containers in the shape of rectangles are represented on the screen. The name suggests containers of liquids, reflecting the beakers filled with water and alcohol students use in laboratory experiments, but students are told the rectangles could as easily represent chunks of solids (aluminum, steel) or containers filled with gases, and the information presented is general enough to apply to all cases. CONTAINERS focuses less on molecules than on their (disorganized) energy, i.e., thermal or heat energy. The amount of heat energy is represented by a certain number of dots, and the temperature (when a single substance is considered) by their density. In the normal mode, the molecules are not represented in the container. The program is interactive and serves several purposes: it illustrates visually the difference between heat and temperature, shows the relation of heat, mass, and temperature, and simulates conduction. The VIEW option allows users to view the molecules in motion (and thus to verify that higher temperature means faster moving molecules; it also reminds them that the energy dots do not represent molecules). The model includes problems for students to solve.

The second model, COLLISION, is meant to give students the sense that the heat exchanged by two bodies at different temperatures is really an exchange of mechanical energy between fast- and slow-moving molecules, thus giving meaning to the "energy dots" in the previous program. The model illustrates the exchange of energy that occurs when two molecules collide. Two molecules collide on the screen. Each contains a certain number of energy dots, proportional to their speeds on the screen. After the collision, the numbers of dots each has changed, although the total numbers of dots stays constant. Students are told that the amount of heat exchanged is represented by an exchange of dots between the colliding molecules, and that those dots are the same dots used in the previous model. Thus, this program shows visually that heat is motion energy and accounts for thermal equilibrium in terms of molecular collisions.

KINETIC & INTERNAL ENERGIES, the third program, like the previous program, shows collisions between two molecules but it also accounts for two "types" of energy, the kinetic energy in the center of mass of the molecule (directly related to temperature) and the vibrational and rotational energy inside the molecule (here called "internal" energy, in accord with "simplified physics," below). The property of substances that makes them respond differently to heat input and output is called specific heat. The program demonstrates that the ratio

between the two kinds of energy is constant for a given substance and accounts for specific heat.

Thus, in these models heat as mechanical energy has a dual visual representation: molecular motion and energy dots. The COLLISION model and the VIEW option of the CONTAINERS model establish a direct connection between the two representations. The CONTAINERS models itself builds on that relation, but uses only the energy dots, which allow quantitative laws and phenomena to be displayed.

"Simplified Physics"

Like any model builders, the group has struggled with the issues of truth and simplicity; in the case of heat and temperature the two do not seem to go together. Rather than include in an unclear way certain complex ideas (e.g., average kinetic energy, heat as energy in transfer, internal modes of motion, and so on) which are beyond students' understanding at this point, the group chose for clarity to "simplify" some principles of physics, deliberately violated them (e.g., all the molecules have the same energy in the models) while addressing others in enough depth to make them graspable (specific heat).

In these models heat is spoken of as <u>in</u> a container, even though most textbooks define heat as the energy exchanged between two bodies at different temperatures and strongly state, "There is no heat <u>inside</u> a body, heat is only a <u>transfer</u> of energy." The group believes, however, that it is acceptable, at least in ninth grade, to speak of the quantity of heat in a body, that is, to regard heat aa a kind of internal energy. This simplification helps maintain the focus on the important difference between heat and temperature -- extensivity versus intensivity.

Similarly, although temperature is not simply the density of heat, the idea that it is captures an important difference between heat and temperature which later can be elaborated, after students are comfortable with the extensivity of heat. One could view it as an intermediate conceptualization, a stepping stone for the students. Indeed, when a single substance is studied, the average kinetic energy of the molecules (i.e., temperature) and the average energy in the internal modes of motion covary, so that heat density is proportional to temperature. In line with such thinking, the first stages of teaching refer to heat as "energy of motion of the molecules," ignoring the distinction between kinetic energy and internal modes of motion.

A further simplification in the models is the pretense that all molecules in a body at thermal equilibrium have the same speed, ignoring the distribution of molecular velocities.

All teachers know it is sometimes difficult to make things clear without "lying," and "simplified physics" involves choosing to lie. Not lying, while attempting to keep things simple, often leads to vague or confusing statements which impair learning. A computer model cannot be vague: molecules either have

the same speed or they do not. The choice made in developing these models was not to incorporate aspects of theory unnecessary for learning the main distinctions students need to learn. Because the models are presented as abstractions, as simplified representations of reality, and in particular because they are revisable, such simplifications, however heretical they may appear to experts, will not hurt students.

Pilot Study

The Heat and Temperature Group tested the molecular models in a pilot study in the spring semester of 1987. The goal of this study was to test whether the models made sense to the subjects, helped them to differentiate between heat and temperature, and whether after exposure to the main program the subjects could easily solve the TASKS. The group wanted to gather information, from the comments and spontaneous questions of the subjects as well as from their difficulty or ease in understanding particular points or making prediction errors, about the process of reconceptualization. This information was needed to help the group revise the programs where necessary and plan the curriculum.

Fifteen subjects participated. Some were recruited from ninth- and tenth-grade science classes in two middle-class suburban high schools, where they were selected by their teachers from volunteers in order to represent a range of ability in science, from grade C to A. They were interviewed at their schools, in groups of three. Others were eighth- and ninth-grade paid volunteers taking part in a study on the use of microcomputers in science education conducted by the Technological Education Research Centers (TERC, Cambridge, Mass.). They were interviewed at TERC, also in groups of three. Five other subjects, paid volunteers, were adults, college students and Harvard employees, with no formal science education beyond general high school science; one adult subject was interviewed individually, the others as a group. After preliminary questions to assess their understanding of heat and thermal equilibrium, the subjects were presented with the first two of the three initial models, COLLISIONS and CONTAINERS. The interviewers' approach was a mixture of didactic and Socratic: they conversed with the subjects, first showing them the programs, then asking them to use them themselves. The subjects were given some information directly and their queries were answered, the interviewers leading them to discover some of the principles embodied in the program (e.g., that temperature is represented by the density of dots).

Results

The tenth grade students, previously exposed to the topics of heat and temperature, came to the intervention with a rich store of beliefs and misconceptions about thermal phenomena. They knew that heat is energy, that molecules move faster when the temperature is higher, and had some understanding of the heating process, but they showed the typical misconceptions about heat and temperature. They said that temperature measures heat, lacked a

concept of amount of heat, and solved the initial problems by using an intensive concept of heat, thereby giving evidence of their lack of differentiation between heat and temperature. One showed a prevalent misconception: that as molecules in a colder body start to move faster they collide more and thus generate heat (by friction) which raises the heat of the body.

So long as the focus in the CONTAINERS program was on equal mass containers, they grasped the information easily, but when the case of unequal containers with the same total energy (i.e., number of energy dots) was introduced, they could not agree on whether the containers had the same heat. They understood that dot density was proportional to temperature (probably because this fitted their misconception of "more crowded = hotter"), but then were faced with a paradox: if dot crowdedness is temperature and temperature measures heat, what does the total number of dots represent?

The group slowly evolved toward understanding that the total number of energy dots represents heat and therefore that temperature is not a measure of heat. It is not easy to determine how this occurred (nor was that the purpose of this endeavor), but a combination of interconnected factors seems to have established a sense that total number of dots had an explanatory role in the model which was not unlike the role heat sometimes played in their own theory. Their eventual acceptance of the idea that the total number of dots represents amount of heat resolved some paradoxes in their theory and that may have contributed to their reconceptualization. Once established by one student, the differentiation was understood by all and "there to stay" (at least for the duration of the study!).

The ninth grade students had just studied heat and temperature in science class, yet in the preliminary questions they showed little understanding of thermal expansion and none of either the nature of heat or its extensivity. These students were struggling not only with a lack of differentiation between heat and temperature but also with a lack of understanding of intensive and extensive quantities. They were not even clear about the difference between the total number and the density of the dots (the previous group was always clear about the latter): "more dots" seemed to signify an undifferentiated meaning of "greater amount of dots/more crowded dots." Yet, in spite of their serious and prolonged confusion, at the end these students seemed to understand the model and, in particular, the mapping between heat and number of energy dots on one hand and temperature and density of dots on the other.

Among the adult subjects, the one with the least background in physics and mathematics had, as might be expected, the most difficulty; this subject had to become familiar not only with the model but also with both a novel way of thinking and with concepts the others already had or at least had been exposed to. All the subjects thought temperature was the measure of heat, all understood thermal expansion at the molecular level, and none knew what heat was. One mentioned amount of heat in the appropriate context, but was still open to the possibility that heat and temperature were the same. They had no trouble with

the COLLISION program, nor, so long as equal masses were used, with the CONTAINERS one. For the most part the subjects learned, progressively, the quantitative relation among total number of dots, dot crowdedness, and mass, and, again, their acquisition of the notion of the extensivity of heat seemed to have been aided by envisioning the energy of all the molecules.

Conclusions

The teaching intervention was more successful with students with good scientific reasoning who did not have strongly entrenched misconceptions. Generally, the ninth grade students interviewed, owing to their logico-mathematical difficulties (not knowing how to set and test between two rival hypotheses, not distinguishing between intensive and extensive quantities), took longer to assimilate the model well. Tenth-grade students, perhaps in part because they were older or because they had more background knowledge (familiarity with the molecular model from the study of chemistry), understood the model more easily and were clearer about what they did not understand. The model being presented finally defeated their misconceptions partly because the subjects were metaconceptually aware of the need for revision. Overall, the results were very encouraging: most subjects could, in a few hours, differentiate between heat and temperature, explain the molecular basis of heat transfer, and conceptualize and solve a variety of problems. That the models appeared to accomplishin a few hours what traditional teaching fails to do in several days is a positive result.

Some difficulties with the software were revealed and will be remediedhat will be remedied . Subjects confused dots and molecules; the remedy is to have a program that representseddots and molecules on the screen either separately or simultaneously, depending on need (as is possible to some extent in the CONTAINERS model). New software developed by the group, ENERGY DOTS IN MOLECULES, fills this need. Several students showed difficulty distinguishing between, and relating, intensive and extensive quantities. A separate lesson about this topic may be helpful; the case of weight and density may be a good training case. The hardest topic was amount of heat as represented by the total number of energy dots. (Specific heat was not tested.) Some of the findings from the pilot study as well as some aspects of the models (see "Simplified Physics") suggest incorporation of metaconceptual points into the the curriculum.

Among developments in software, aside from the new ENERGY DOTS IN MOLECULES, are some modifications to the CONTAINERS program. It will be enriched with an option on CONDUCTION. The option VIEW will be expanded, so the user can switch back and forth between two windows to compare molecular velocities in two containers. A new task, for temperature prediction, will be added (for a total of nine tasks). The KIN. & INT. ENERGIES program also will be modified, to add multiple visual representations for energy circles; the red and green colors previously used proved confusing, because red and green were also the colors coding internal and kinetic energies.

A new program is being developed, SPECIFIC GRAM, to treat an aspect of specific heat textbooks tend to ignore, as did the previous models. The group originally excluded a focus on number of molecules in the model of specific heat, on the premise that adding another variable would add unnecessary complexity. For the sake of accurate physics, however, what needs accounting for is that even if all the molecules in the world had the same structure and thus the same ratio of kinetic to internal energy, different substances would still have different specific heats, because they would have different molecular masses. There are, then, two "molecular" reasons for differences in specific heat: molecular mass, which the new software will account for, and molecular structure, accounted for in the previous model; together, the two comprise a curriculum to teach specific heat.

The Nature of Science

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The work of the Nature of Science research group assumes two goals for a science curriculum: (1) to help students learn concepts and theories in biology, earth science, chemistry, and physics and (2) to help them understand the nature of scientific knowledge and reasoning. The group developed materials for junior high school students to lead to an appreciation of scientific knowledge -- of the construction of theories and of the cumulative, often groping progress toward understanding natural phenomena. Previously they had (1) identified what in their view students at this point ought to understand about the scientific enterprise; (2) assessed current middle school curricula by analyzing text books and widely used tests; (3) assessed the conceptions of science held by late elementary school-age students; and (4) designed and assembled materials for a month-long unit in the seventh- and eighth-grade science curriculum (see ETC Technical Report TR86-11, *What middle school students do, can, and should know about the nature of science: Progress report*, October 1986, for a full description of this unit). The group found that traditional curricular units on the scientific method for junior high school students emphasize the collection of reliable data, teaching students to identify the independent and dependent variables in experiments and identify cases where two independent variables have been confounded. These units, however, do not teach students that the purpose of scientific experimentation is theory building. Their narrow focus on the "process skills" -- observation, classification, measurement, the planning and execution

of controlled experiments -- has generally helped students explore the *how* of scientific reasoning but neglected the *why*.

In 1987 the group probed junior high school students' understanding of the nature and purpose of science and explored whether an intervention on the nature of science could change the initial conceptions, as well as demonstrable misconceptions, of seventh graders about the nature of scientific knowledge and the purpose of scientific inquiry.

Previous Work

The unit developed by the Nature of Science Project was tested in the school system of Newton, Massachusetts. A month-long field trial of the experimental curriculum was run twice. The central questions were whether students would follow the points about the nature of scientific inquiry made in the experimental unit and at the same time master the collection of reliable data, the goal of the standard unit. Study I compared the feasibility and effectiveness in whole classrooms of the experimental unit with those of the school system's standard unit on this topic, known to be successful in its own terms. Study II used a revised version of the experimental unit and revised pre/posttests and interviews.

Study I: Comparison of a Standard Unit and the Experimental Unit

The seventh-grade science curriculum in the Newton schools introduces students to the terminology of the experimental method -- hypothesis, independent, dependent, and controlled variables, data, measurement, and so on -- through a classroom demonstration and home experiment in which cabbage juice is mixed with various substances, producing changes in color. Subsequent activities include a series of experiments to answer specific questions (e.g., what is the effect of soap in water on the absorbency of paper towels?). Working in small groups, students formulate a hypothesis, design a test of it, carry out the experiment three times (for reliability), and draw conclusions from the data, in every case indicating the independent, dependent, and controlled variables.

The Experimental Unit. There were two major parts to ETC's experimental curriculum, a two-week sequence on yeast followed by a one-week sequence on linguistics, each making different but complementary metaconceptual points about the nature of science. The sequence on yeast exemplifies the cumulative character of science and the process by which experimentation leads to an understanding of a particular phenomenon. It makes the same points as the sequence on cabbage juice in the standard unit (the need for measurement and for controls) but ties experimentation to *understanding* what yeast is and *why* when mixed with water and sugar it produces a gas. Among the metaconceptual points included in this unit are that explanations are always guided by current theories and that building better theories involves revising those previously held. In the linguistic sequence students began by trying to account for a particular syntactic phenomenon -- why "want to" can be contracted to "wanna" in the sentence "I want to go" but not in "Who do you want to go?" While generating hypotheses and

searching for counterexamples to their generalizations, students learn metaconceptual points about the role of counterexamples in testing and constructing theories.

The ETC unit covered most of the points included in the standard seventh-grade curriculum unit used in the Newton schools and added conceptual challenges. The study involved four seventh-grade science classes usually taught by one teacher, two using the ETC unit, two as controls. Students in two of the four classes were considered by the school to be average and above average in ability, those in the others were considered average and below average. The experimental unit was used in each type of class. For the purposes of teacher-training and controlling for teacher differences, classes were taught alternately by the regular Newton teacher and by the project member, with the regular teacher always teaching the first control class and the project member the first experimental class. This procedure allowed the one not teaching to observe the less familiar lesson before having to teach it.

Software. In Study I the experimental sequences were preceded by a one-week software sequence. Several software packages were reviewed and two chosen, *The King's Rule: Mathematics and Discovery* (Sunburst Communications) and *The Scientific Method* (Cygnus Software). *The King's Rule* introduces students to the process of forming hypotheses and testing, revising, and, in particular, falsifying them; it presents students with a triad of numbers and asks them to formulate a rule that generates the triad. *The Scientific Method* allows students to work with various experimental conditions and observe the effects of different variables.

Assessment. Before and after the intervention a small number of students were interviewed and all students in the four classes were given written tests consisting of 26 items adapted from the three tests judged most suitable from the group's survey of published tests of inquiry skills (for a description of the survey and its findings, see ETC Technical Report TR86-11, *What junior high school students do, can, and should know about the nature of science: Progress Report*, October 1986). Items were selected to assess points covered in both the experimental curriculum and the standard one on the nature of science and scientific inquiry and on the logic of experimentation. Points emphasized in the experimental curriculum were assessed by items on the nature of science and scientific inquiry (goal of science, testing of ideas, how questions lead to new questions) and on the nature of theories (theories as explanations for natural phenomena and as mental constructions). Other items assessed students' understanding of the components and logic of experimentation covered by both curricula but central to the control unit (identification and the nature of hypotheses, experimental design; identification of variables, control of variables; and measurement).

The interview was designed to probe and characterize students' understanding of the process of scientific inquiry both before and after exposure to either curriculum. Fourteen students were interviewed, eight of average or

below average ability, six of average or above average ability. The comments and criticisms of the teachers, made during the intervention as well as in informal interviews after the experiment was over, also were collected.

Results. As hoped, the preliminary trial of the experimental unit demonstrated that it was comparable to the standard unit on the scientific method. Analysis of the pre/posttests revealed a modest, statistically significant improvement (9%, n=76, $p<.0001$) for both the experimental and control groups. There was no significant difference between groups over all items or on item groups emphasizing experimentation or the nature of science specifically. Analysis of the interview protocols enabled the group to develop a coding system and repair two difficulties in the design of the interview. First, although each question in the interview addressed a particular element of scientific inquiry, none addressed their relation. Second, although students often used such terms as "research," "test," and "hypothesis" in their responses, the interview failed to probe what they thought such "big words" meant. Since the interview, like the written test, was not tied to either curriculum, it may have been too general to reveal subtle differences in students' thinking. Through its shortcomings, it guided the design of the one used in the second trial of the experimental curriculum.

The software sequence proved disappointing, even though students enjoyed playing with computers. *The King's Rule* was more successful than *The Scientific Method* because students were engaged by the problem of guessing the rule and seemed to learn something about forming hypotheses, but the software did not allow teachers to make points about revising hypotheses according to evidence or about the search for counterexamples. As a result, students' understanding was limited. *The Scientific Method*, although effective in making individual points, did not consolidate them. The group concluded that teacher could have taught the same lessons more effectively than the computer.

Although the experimental unit was manageable and teachable in the regular classrooms of the preliminary trial, it required the special conditions of the study -- two teachers and observers always present -- to make it so. Teachers suggested that the experimental unit should include more written work to consolidate classroom discussions. On the basis of the experience of this trial, the group was able to revise the unit and create support materials to make it implementable by a single teacher.

Study II: The Revised Unit --Closer to a "Real-world" Trial

The second trial of the revised Nature of Science unit was conducted at the Hosmer East School in Watertown, Massachusetts, in five seventh-grade classes. All were normally taught by the regular teacher who was given lesson plans but worked independently, without a member of the research project as either model or co-teacher. Homework and lab sheets were devised to remedy the insufficiency of written work for students in the experimental curriculum, prompting students to think about the ideas and experiments between lessons.

Other than these general modifications, specific changes made in the structure of the month-long unit included: (1) the addition of an introductory as well as a wrap-up lesson; (2) replacement of the segment using computer software (*The King's Rule* and *The Scientific Method*) with another using an interactive videodisc segment, *Seeing the Unseen* (see ETC Technical Report TR87-4, *A prototype science interactive videodisc: Research on in-school use*, April 1987);and (3) revision of the yeast sequence so a teacher might manage it unassisted. Because of the teacher's time constraints, the linguistics segment was omitted in the second trial.

A written test, a revision of the test for Study 1, was developed to assess the extent to which students learned specific points in the unit. The interview was revised to reflect metaconceptual points covered in the experimental unit. Items fell into several particular areas -- (1) Nature and Purpose of Science and Scientific Ideas; (2) Development of Ideas (3) Identification of Hypotheses; (4) Nature and Purpose of Experiments; (5) Guiding Ideas and Questions; and (6) Results and Evaluation -- to allow as full a characterization as possible of the students' understanding at the start. Twenty-seven students were interviewed.

Results. Gains on the six subsections of the written test averaged from 0 to 14%, with greatest improvement in the questions on the Nature of Science and the the Development of Ideas. Subsections on Identification of Hypotheses and the Nature and Purpose of Experiments also showed improvement. No gain occurred in the questions on Guiding Ideas and Questions, even though they reflected the unit's discussion on choosing variables.

To code the interview, researchers defined several dimensions along which students' level of understanding might vary: (1) their understanding of the motivation for scientific activity, from a simple plan to an organized exploration of an idea or phenomenon; (2) the degree to which they were able to define and differentiate among ideas, experiments, and results; and (3) their understanding of the relationships of these elements. In General Level 1, students make no clear distinction between ideas and activities, especially experiments. A scientist "tries to see if it works." The nature of "it" remains unspecified or ambiguous; "it" could be an idea, a thing, an invention, or an experiment. The motivation for an activity is located in the characterization of the activity itself, rather than in the larger context of the construction of ideas. In General Level 2, students make a clear distinction between ideas and experiments. The motivation for activity is verification or exploration of an idea, and, more specifically, the purpose of doing an experiment is to test an idea to see if it is right. In General Level 3, as in Level 2, students make a clear distinction between ideas and experiements and understand the motivation for activity as verification or exploration of an idea. In addition, however, there is an appreciation of the relationship between the results (especially unexpected ones) of an experiment and of the idea being tested. An idea is evaluated in terms of the results of a test and may be changed or developed in accord with these results.

Here the results were much more dramatic than on the less sensitive written test. Before instruction with the experimental curriculum, students either failed to understand the questions or at best demonstrated a first-level understanding of science. After the unit, the understanding of every student interviewed increased, and improvement averaged half a level. Mean level increased from 1.0 to 1.55 ($n=27$, $p<.001$). Three-quarters of the students scored at level 2 or higher on at least one section. This study did not address the question of whether these levels are analogous to *stages* of understanding, as in Kohlberg's stages of moral development.

Again, the use of technology to impart metaconceptual knowledge proved the least successful part of the intervention and the videodisc segment could have been dispensed with entirely. Since the lessons could be imparted without the particular software and videodisc, they were not considered helpful. The group believes that software used to build understanding of particular phenomena would also build understanding of inquiry, such as that of the Weight/Density and Heat/Temperature projects, White & Horowitz's *ThinkerTools*, and others.

Learning science is difficult, because restructuring knowledge and making conceptual change are not easily accomplished. A current contention of the group, not tested directly in these studies, is that if students understand the process of developing scientific knowledge and its constructed nature, they will be in a position to understand the evidence that will lead them to restructure their own knowledge.

RESEARCH IN MATHEMATICS EDUCATION

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In the belief that systematically linking and manipulating computer representations of mathematical concepts help lay a foundation for richer and more flexible *cognitive* representations, ETC's mathematics education projects have exploited the computer's potential to display multiple dynamically linked representations -- such as graphs, algebraic expressions, and geometric figures. By providing environments within which students can easily manipulate these representations, technology can help students ascend a learning ramp from easily grasped concrete representations -- such as pictures and numerical tables -- to more abstract but mathematically more powerful ones, such as coordinate graphs and algebraic equations.

Using such representations, the Word Problems Project has developed a series of software environments to help elementary school students master the web of ideas connecting multiplication, division, ratios, and proportions. The Geometry Project, using software that allows students easily to construct and measure geometric figures, has studied high school students' understanding of the role of conjecture and proof in formal mathematics, particularly plane geometry. Similarly, the Algebra Project has used multiple representation software to investigate high school students' understanding of graphical representations of

algebraic functions. Together, these projects suggest ways of breathing new life and new understanding into the mathematics curriculum from the upper elementary through the high school levels.

Geometry

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In Year Four, the Geometry Project continued its explorations of the use of the *Geometric Supposer* as a tool for introduction of inductive reasoning into the regular geometry curriculum. Its work followed two lines of inquiry: (1) study of students learning geometry through constructions and conjectures and (2) study of the complexities involved in implementing such an open-ended approach in regular classrooms and schools.

These lines of investigation were pursued in separate but overlapping studies. The inquiry into student learning consisted of two teaching experiments, the first a detailed examination of students' empirical/inductive reasoning and deductive reasoning in response to a teaching approach that juxtaposed constructions and deductions in an effort to reduce students' confusions about the relationship between data and proof. The second teaching experiment attempted to help students master the notoriously vexing topics of ratio and similarity in geometry. The inquiry into implementation issues used the ETC Laboratory Sites Project to examine the personal, professional, epistemological, and managerial issues associated with teachers' effective integration of a powerful but demanding type of software into a range of regular classroom situations.

As an adjunct to these studies, the group developed a questionnaire on attitudes toward mathematics and mathematics learning which was administered to *Supposer*-using and non-*Supposer*-using students.

Teaching Experiments

The Similarity Unit

An understanding of similarity relationships is central to any geometry course, yet students have a well-documented difficulty in grasping the concept of similarity. Some of their difficulty stems from common sense notions and previous perceptual experience. In geometry, shapes are defined as similar when they have the same shape but not the same size. In practice, however, this definition is vague: what does it mean for objects to be the same shape? are all

right triangles the "same shape" and therefore similar? The group's 1985-86 study designated three areas of particular student difficulty: (1) understanding of ratio and proportion as an aspect of similarity, (2) understanding of the relation of change in the lengths of sides of similar figures to the measures of quantities in other dimensions, and (3) proportions (among the lengths of sides) in right triangles with an altitude from the right angle vertex.

As Year Four began the group was completing work on a teaching unit designed to address these difficulties which was then tested in two high schools. A pre/posttest, adapted in part from the Chelsea Math Test series, was administered to both classes and to a comparison class closely matched in ability and curriculum. The experimental unit consisted of eight tasks designed for use with the *Geometric Supposer* in a computer lab during class time. These tasks were added to the teacher's existing similarity unit and carried out through regular classroom activities. A research group member was present for three of the four geometry classes held each week. The comparison class did a unit on similarity without using the *Geometric Supposer*. In addition, the group developed a four-part clinical interview to probe students' notions of similarity, which was used with students selected from the experimental classes to represent a range of abilities.

Results

Students who have the first difficulty, a misunderstanding of ratio and proportion in similarity, often exhibit the difficulty when given a triangle and asked to make a similar triangle by extending the sides of the original triangle. They use *an incorrect additive strategy*, adding an equal length to each side of the figure, rather than a multiplicative strategy, which would preserve the figure's proportions. In this study, researchers found that both traditional similarity units and units that focused students' attention on this incorrect strategy were effective in helping some students change strategy. Data from the study also support the idea that the additive misconception is more prevalent in production tasks involving enlargement than in numerical proportion problems. This finding suggests it is important to search a problem for aspects of the geometrical configuration that lead students to use an additive strategy; even those who demonstrate an understanding of a multiplicative ratio may, in a geometrical construction task, revert to an additive strategy.

Students' second difficulty, understanding the relation of area growth to growth in other dimensions, is important because previous research has shown this is a difficult area for students, and, indeed, in the classes studied, very few students discovered the relationship on their own prior to instruction. The teachers in this study used two strategies to provide students with the necessary guidance. One provided students with a formula, the other had students try to generate the formula by doing a computer task. Students worked with both two-dimensional figures and solids. By the end of the unit they recognized the different growth relationships that hold for solids, but many could not explicitly apply their knowledge to explain figures. With one exception, they did not

understand that the relationship of sides, areas, and volumes represents one underlying relationship, that, for example, when the ratio of the edges of two solids is 2:1, the ratio of their faces is $(2:1)^2$ or 4:1, and the ratio of their volumes is $(2:1)^3$ or 8.1. When students missed one of the dimensional answers, the ratio of the faces or the ratio of the volumes, the problem seemed to involve a reorganization of the perceptual field. These students appeared unable to reorganize their perception of the whole to highlight the missing dimension.

Regarding students' difficulty with corresponding ratios in right triangles, the study tested two hypotheses: (1) that students have difficulty recognizing the similarity of triangles that must be flipped to be superimposed with the corresponding sides aligned and (2) that students find similarity relationships in right angles difficult because in the typical configuration the altitude plays a different role in each of the three triangles created by dropping an altitude from the right angle. Results, however, were inconclusive. Evidence from the interview tasks did not support either hypothesis strongly.

The activities used in this study were effective in identifying student misconceptions. They underscore the difficulty of similarity and point out that much more time could profitably be devoted to similarity and scale during a high school geometry course. In addition to insights into students' understanding of similarity, the study provided some evidence for a more general claim, that when microcomputer tools are used in an approach of guided exploration the computer lab session can be an important and valuable tool for research on students' understanding.

The Proof Unit

The Proof Unit and a questionnaire used to understand students' views of proof were designed and tested. With lessons taught approximately twice per week for four weeks, the Proof Unit, unlike the Similarity Unit, was designed to be interspersed among lessons on other topics; one day each week was spent in lab activities, the other in class discussion. The teacher materials for this unit consist of a taxonomy of problems as well as a series of particular problems from which teachers may select. In addition, teachers receive loose scripts to guide the class discussions. Data were collected by observation, by interview, and with pre- and post-questionnaires. Empirical work in this area will continue. As of January 1988, these data are still being analyzed.

Implementation Studies

The inquiry into how teachers integrated the geometry innovation into their existing curriculum and teaching style was carried out in conjunction with the Laboratory Sites Project; discussion of goals, methods, and results will be found in that section of this report.

Other activities

This year the group developed and field tested a questionnaire, based on an instrument developed by math education researcher Elizabeth Fennema at the University of Wisconsin, to examine the possible effects of use of the *Geometric Supposer* on students' attitudes -- toward mathematics, toward their own mathematical abilities, toward the role of logic in mathematics, and toward their sense of control over their own learning. The questionnaire was administered at the end of the year to students in the experimental and comparison classes, as well as to students who had used the *Supposer* a year ago; data are being analyzed.

Word Problems

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This group's early analyses, and other recent studies of students' difficulties with word problems, have attributed the central difficulty to a lack of rich and flexible cognitive models of the operations of multiplication, division, and the associated idea of intensive quantity. Intensive quantities -- sometimes referred to informally as "per quantities," such as candies per bag or miles per hour -- seemed to be at the nexus of ideas and problems that students find most difficult. The group therefore began developing a series of software environments to build students' understanding in this area of mathematics. The software uses several different mathematical representations, each supporting particular aspects of reasoning with intensive quantities and, more broadly, within the conceptual field of multiplicative structures. They are combined into a series of learning environments, designed as a ramp to help students move from initial concrete conceptions to more abstract and mathematically more powerful ones.

An important, perhaps defining, characteristic of the software environments is their systematic linking of concrete representations, beginning with iconic (pictorial) ones, to the more abstract representations (numeric tables of data, coordinate graphs, and algebraic expressions) upon which much of advanced mathematics is built. The Word Problems Group uses these representations in the belief that appropriate actions on systematically linked computer representations help lay the foundation for the development of rich and flexible *cognitive* representations. The environments are intended to be usable

over several years and grade levels, spanning the core multiplicative mathematics curriculum from the middle elementary grades through the junior high school level (which includes multiplication, division, ratios, and proportions).

Software Development

This year the group refined the software environments developed during Year Three and extended their efforts in two new directions. First, they created Icon Calculation Environments to introduce students to the most concrete representation and to support computation based on simple acts of matching, grouping, and counting. Second, they initiated development of a continuous quantity environment, which will be parallel in structure to the discrete environments. In addition, they developed equation windows to extend the learning environments toward algebraic representations of intensive quantities. Users will be able to open these equation windows in both the Linking and Multiple Representation Missing Values environments and, thus, to do proportional reasoning using algebraic expressions. A feature of the software provides an innovative introduction to the critical notion of *variable*, linking it with the representations already familiar to students.

With these innovations, the existing software is organized into four environments: Icon Calculation Environments, Linking/Incrementing Environments, Missing Values Environments, and Sampling & Comparison Environments. A fifth set, the Continuous Environments, is still under development.

The **Icon Calculation Environments** (ICE) form the most concrete level of the "software ramp." One family of ICE supports calculations with a single set of icons, acting as a "game board" on which students can drag icons or groups of icons from a reservoir and distribute them freely in a rectangular array of cells. The computer provides simple numerical information on their actions -- how many icons have been distributed, how many cells have been used, and so on. The second ICE family supports calculations with two sets of icons, as in concrete, iconic versions of ratio reasoning tasks. In this context, ratio reasoning, historically assumed to be a difficult process requiring substantial intellectual development, is broken down and carried out using only the fundamental cognitive acts of grouping, matching, and counting.

The **Incrementing Linking Environments** provide an arena for ramping upward from these concrete reasoning environments to the more powerful mathematical representations such as the coordinate graph and algebraic equation. These environments support the basic acts of incrementing and decrementing, allowing students to examine at will the linked consequences of these acts in any or all of four representations: iconic, numeric (tables of data), graphic (coordinate graphs), and algebraic (equations).

Having gained familiarity with these representations and the links among them, students can solve proportional reasoning problems in the **Missing Values Environments**. In this type of problem, the student is given a ratio and a third number; the task is to find a fourth number that fits the given ratio. In the Missing Values Environments, students can try solutions in one representation and check their results in any other representation, often using a concrete representation (iconic or numeric) to check on computations done in a more abstract one (graphic or algebraic).

Ratios are used to describe an internal feature or attribute of a substance, entity, or situation -- for example, the density of a material in grams per cubic centimeter, the speed of a car in miles per hour, or the number of candies per child in a group. Such a feature or attribute is often referred to as an "intensive" attribute, as distinct from " extensive" attributes, such as mass, length, volume, number of items, and so on. Ratios that describe intensive attributes are often referred to as "intensive quantities." The modeling of intensive attributes by intensive quantities is addressed in the **Sampling & Comparison Environments**, which also support the *comparison* of intensive quantities, as in problems such as this: if one park's picnic area has 2 trees per 3 benches, and another's has 3 trees per 5 benches, which is shadier? In this way the environments engage the idea of order in intensive quantities.

Still under development are the **Continuous Environments**, an essential addition because the bulk of the mathematics curriculum beyond the early grades uses continuous quantities. In these environments, the icon display will be replaced by continuous line segments. In addition to containing deliberate transitions from discrete to continuous representations (e.g., using icons strung out as an "integer number line") these environments also use an interface and command structure that is maximally parallel to that of the discrete environments.

Teaching Experiments

As the fourth year began, the Word Problems Group was completing its analysis of data gathered during the previous six months. This analysis fed into the software development activities described above and led to the design of the next phase of testing. To explore whether the software supports the kind of reasoning and cognitive processing the group seeks to promote and whether it functions as intended at the appropriate age levels, researchers used it on a 1:1 basis with a variety of students in both public and private schools near Boston and audiotaped the interactions.

The software was modified according to the results of these exploratory sessions and, in the spring, the "upper levels" (Linking and Missing Value Environments) were tried with 12 sixth graders, who worked in pairs with research group members for six sessions. A comparison group of sixth graders from the same school engaged in similar activities but without using computers. A second comparison group, composed of seventh graders, received traditional

instruction in ratio and proportional reasoning. Students in all three groups were also given a diagnostic test on rational number arithmetic, word problems, and ratio and proportion. At the same time, a group of eight third and fourth graders from the same school was observed as they used the the Icon Calculation Environments. The finding from all these activities was that all the different levels of the software made sense to the students toward which they were directed and helped them solve problems and think about the mathematics of intensive quantity and proportion. The software also proved interesting and engaging for these students.

The materials developed for the experimental group of sixth graders provided the basis for a dual-level whole-class teaching experiment conducted during the summer of 1987. This experiment at an urban school involved two groups of students for ten sessions spread over three weeks. The lower level involved a small group of fourth and fifth graders who were very weak in mathematics; of the four students in this group who participated in the full intervention, three were classified by their schools as learning disabled, and the fourth was a nonmainstreamed mentally retarded student. The upper level involved eight sixth and seventh graders and one fifth grader, all classified as average or slightly below average in mathematical ability but with generally below average school performance records.

Sessions consisted of a planned mixture of teacher-centered classroom discussion activities and laboratory activities, although instruction with the younger group tended to be tutorial because of the small size and developmental level of the group. Both groups began work with the Icon Calculation Environments. The younger group worked in this environment until nearly the end of the intervention, when they began to solve missing value problems using tables of data as well as the iconic representation. The older group progressed to solving missing value problems in the multiple representations environment.

The group audiotaped the pre/posttest interviews for all students and tracked five students closely, four from the older group and one of the learning disabled students from the younger group. An observer worked through the lessons with each of these students; case studies of the students' reasoning strategies and use of the software are now being made on the basis of these observations and the pre/posttests. Follow-up sessions in February will examine the current nature of students' mathematical reasoning with multiplication and division word problems and probe areas pointed to by the case studies.

Though data analysis was not yet complete by the end of Year Four, three findings were apparent:

(1) Bringing about meaningful conceptual change in an extended domain such as multiplicative structures requires interventions measured in years, not days.

(2) The development of a viable, cognitively based foundation for as large a portion of the school mathematics curriculum as the Word Problems Project seeks to address likewise requires an extended period of time.

(3) The use of sophisticated, representationally rich learning environments in a realistic classroom setting involves close interaction between the use of the computer software as a set of interactive learning environments *and* as a materials-generating system for teacher-centered activities.

This last finding has practical implications for use of the software ramp in classrooms with only one or a few computers. The group is continuing analysis of the summer's work and extending the software environment to encompass continuous quantity.

Algebra Project

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Algebra software that links symbolic and graphical representations of functions is proliferating because of a perceived need for increased emphasis on graphing in the curriculum and because computer technology lends itself well to this application. Common sense supports the notion that multiple representations will aid understanding. Static media can support only clumsy, serial, time-consuming translations across representation systems. Microcomputers, through appropriate windowing and interfacing, can support multiple, simultaneously linked representations, rendering an immediate, explicit, and obvious correspondence between representations where actions taken in one can be exhibited in others. In the algebra environment, multiple linked representations supply mathematical redundancy and enable teachers to emphasize some aspects of complex ideas, while playing down others, to support different forms of learning and reasoning. Increasing redundancy reduces the ambiguities potentially present in any single representation. It seems reasonable

to suppose that the cognitive linking of representations creates a whole greater than the sum of its parts, just as binocular vision is more than a simple sum of perspectives, allowing the student to "see" complex ideas in a new way and to move effectively among them. Representations must be chosen carefully to ensure that the learning environment supports rich sets of actions that will expose underlying invariances and enable the student to weave a flexible and enduring web of mathematical meaning.

The Algebra Project began as an outgrowth of a project supported by Education Development Center, a member of the ETC consortium, to develop software. Its work during this, its first year, was essentially broad and exploratory (see ETC Technical Report TR88–4, *Mathematical, technical, and pedagogical challenges in the graphical representations of functions*). The group worked with prototype software (designed by Judah L. Schwartz and Michal Yerushalmy) called the "Function Analyzer." One central innovation of this software is its ability to track actions: putting the computer in charge of the linking process allows the system to provide multiple representations of actions as well as objects. Another central innovation is its ability to support actions initiated on the graphical representation of functions, rather than strictly on the algebraic representation. Use of this algebra software environment with students raised a number of questions which the project took on as targets of difficulty. The environment allows equations to be manipulated and solved graphically, and functions to be constructed and modified as graphical objects, with actions in one representation following in parallel in the other. The microcomputer handles the computational activities required to translate actions, leaving the student free to perform them and to monitor the consequences across the representations.

Initial Investigations

Though the Algebra Group's goal, exploration of the extent to which multiple representation software can improve the teaching and learning of algebra, has remained constant, its approach has changed significantly over the course of this year. In their initial investigations, researchers used clinical interviews and observations to probe students' thinking as they tried by manipulating the terms of equations and observing the changes in the graphic representation, to discover the polynomial expressions that had created particular graphs. Because viewing a graph on a screen or in a textbook illustration is akin to viewing a scene through a window -- the viewer sees only the portion of the graph visible in a given figure -- students often misinterpreted graphs. For example, confusion arose from the facts that: (1) vertical and horizontal translation of lines cannot be distinguished; (2) asymmetrical scale changes alter the visual impression of the slope of a graph of a linear function; and (3) symmetric scale changes (e.g., "zoom") affect the visual impression of the shape of a parabola without doing so for the "shapes" of lines; and so on. These findings are of practical importance to designers of software and curricula, and the group was impressed enough with these findings to redesign its research plan to focus on the relationship between

the software environment and the user, especially on how students perceive and interpret graphs.

The group reviewed the literature on how students understand coordinate graphs. More was written about graphs in which time is the independent variable (these are not used for algebraic functions) than about cases in which the relation between the variables was an arbitrary mapping, but there was too little relevant material on which to build directly. Overall, the group concluded that the findings from this research were not clear enough to allow them to build directly on previous work. Rather, clinical work was undertaken to clarify students' responses to the new software and provide direction for more focused inquiries. Researchers developed observation and interview strategies, pencil-and-paper tasks, and worksheets to examine areas that confuse students: the meaning of discrete points in a graph, intuitive or analytic strategies for understanding graphs, and scaling. Eventually the first two areas were subsumed under the third, and scaling became the focus of the group's research.

As part of this diagnostic work, the group also tested students on their understanding of graphs of real-life events, which included such tasks as graphing speed by distance for a bicycle going over a hill. The group administered a test based on an instrument developed by Technical Education Research Centers (TERC) to roughly 50 students from sixth to twelfth grade, and found fewer errors than in TERC's previous study, justifying further investigation into whether the difference arose from perceptual problems or presentation issues. To probe this issue, the group developed a version of the test that differed slightly from the one used in the TERC study and administered it to roughly 70 students, again sixth to twelfth graders. Again, students made fewer errors than in the TERC study, but because their errors were mainly of a particular type they seemed to point to something meaningful. In attempting to graph a relationship, students tended to graph perceived events, rather than quantities -- a kind of charting that needs no scale. Thus, the group's interest in scale remained at the fore.

Studies of Students' Perception of Graphs

To help students overcome confusions about graphs, the group developed problem-based teaching materials for the most important of the diverse paths that instruction might follow. These materials were used in interviews in which researchers could present a situation and ask questions about it. Because no single task can render sufficient evidence for diagnosis of a student's difficulties, the group used a variety of tasks consisting of two general types: diagnostic items which indicated the state of the student's current understanding and process items which permitted the teacher or researcher to observe the process of acquiring new knowledge. Most of the probes center on some particular hypothesis concerning confusions students have regarding graphs and functions; owing to this focus most of the probes served equally as the basis for interviews or teaching interventions. Some tested whether a student could interpret and create real-world graphs, others explored the connections students made between a

complete graph and the symbolic representation of the function that produced it, and still others dealt with issues of shape and scale. When researchers used these materials in clinical interviews, the researcher's role was to encourage thinking aloud, to tape record all responses, and, where necessary, to ask questions to clarify the student's thoughts or procedures. Used as lessons, the materials were designed to give students intuitive and analytic strategies to improve their understanding of scaling and of discrete points on a graph. One set of materials, for example, asked them to explore what the b coefficient does in the expressions $y = ax^2 + bx + c$; another asked them to predict what each equation would look like as a graph.

Although the group's research focused on problems of scale, other related issues could not be completely ignored. For example, in interpreting graphs, students are often inappropriately influenced by such irrelevant perceptual features as the angle at which a linear function intersects the frame of the graph. The overall shape and magnitude of a translation from one graph to another, the direction of movement, and the scale of the graph all may become ambiguous when an object of infinite size is viewed through a finite window and has a smooth shape devoid of readily recognizable subelements. Some ambiguities are also caused by the interaction between the scale of the graph and the scale of the window.

A Word about the Role of the Computer

Without a computer students must be involved at every level of producing a graph before experiments can be performed on it or with it. With a computer, most of the work of constructing graphs -- point plotting, determinations of scale, identification of special features -- can be done automatically. The advent of abundant computer software prompts questions about issues related to the user interface of the software and the structure of the information it provides. Constraints of the screen, types of support features built in, and modes of graphic presentation create their own environments. Other constraints are demands on student involvement, the speed at which graphs are constructed, and scaling choices. How do these factors affect the way students learn and their perceptions of the relationship between algebraic rule and graph? What new tools are needed to investigate the effect on students of graphing software?

Before computer graphing was available, graphing was so tedious that teachers often allowed students to move rapidly from the process of locating a few points to constructing a continuous graph. Sketches tended to be approximate, and visual connections eccentric. The computer's speed and accuracy now make it feasible for the first time to ask students to *use* the graphs of functions to represent rules they are testing. With the computer students can manipulate either the symbolic or graphical representations of functions, see the manipulations reflected in the other representation, and formulate and test hypotheses about the structure of mathematics behind the displays. This means

new choices not only in the methods but also in the content of mathematics classes.

To date, the Algebra Group has provided a broad view of a complex mathematical terrain, has suggested a theoretical structure, and has raised questions and posed hypotheses. Next year the group will continue to refine its materials for interviews and teaching sessions. While maintaining the focus on scale, it will also maintain an exploratory stance.

RESEARCH IN COMPUTING EDUCATION

Area Coordinator: David Perkins, Harvard Graduate School of Education

From the outset, projects in computing education have focused on the pedagogy of programming, that is, both the role of programming and the use of applications software in education. The Programming Project's study of programming instruction began with an inquiry into the way novices understand the structure and function of the computer and into the kinds of problems they encounter in learning to program. In Year Four, the group continued development and testing of its instructional "Metacourse" designed to help students surmount these initial difficulties. In an investigation into the uses of applications software in classrooms, the Educational Testing Service, which previously collaborated with ETC in research on the potentials of applications software in primary and secondary school education, joined with the Brattleboro Union High School (Vermont) in the Systems Thinking Project, which studied high school students' understanding of a microcomputer-based dynamic modeling language and the usefulness of systems thinking in the teaching and learning of both natural and social sciences.

Programming

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Programming, like mathematics and physics, is precision-intensive, requiring meticulous attention to detail. Again like mathematics, physics, and

most science subjects -- perhaps any subject approached properly -- it is problem-solving intensive, requiring students to solve programming problems. It is, however, like artwork or geometric proofs or writing essays, also "design-intensive," requiring students to construct complex products to do particular jobs, rather than only to find particular answers. Not surprisingly, given this constellation of requirements, novice programming students achieve only limited mastery, even after one or two semesters of instruction.

In earlier clinical work the group identified three general difficulties in novice programmers: fragile knowledge, weak elementary problem-solving strategies, and inadequate confidence and control. Most of the group's work in Year Four centered on studies of the effectiveness of a Metacourse designed to help novice programmers overcome such initial difficulties.

The Metacourse is a series of lessons and modules designed to provide a small number of key concepts and strategies which research has shown only a small number of students acquire on their own. As its name suggests, the Metacourse can be thought of as transcending the content of the normal instruction to provide programming-specific skills and a conceptual framework to guide the exploratory thinking of the novice programmer. It offers a mental model of the computer and how it works, presents strategies for understanding and relating commands to that model and for breaking down complex problems into subproblems, and stresses concepts and tactics to help students deal with difficulties characterized in earlier research. The intervention is organized so teachers can introduce key concepts at intervals, "infusing" them into the regular curriculum as the term advances and students gain in knowledge of BASIC. It differs from conventional attempts to redesign curriculum by this process of infusion, by its metacognitive emphasis, and by merging with, not displacing, an existing course, thus lending itself, more easily than other efforts at curriculum reform, to wide dissemination.

Early in Year Four the Programming Group completed the analysis of results from its spring 1986 study of the effectiveness of the Metacourse design. The analysis was complicated by a chance mismatch in general ability between the experimental and control groups. To make the groups comparable, the most able students were dropped from each, and the data were reanalyzed. Reanalysis revealed that the treatment group outperformed control students on several programming tasks but produced no evidence of transfer to other cognitive skills beyond programming.

Field Test of the Metacourse in Laboratory Sites

Also early in Year Four, the group launched its study of the use of the Metacourse in ETC laboratory sites. Feedback from teachers was used to revise the materials and expand them to nine lessons. Teachers in the experimental group received more than ordinary support for their efforts to adapt new materials to their individual styles and classrooms -- monthly meetings with a research team; frequent contact with a research assistant or Lab Sites project

liaison assigned to the Programming Group; access to communication with ETC personnel and with one another through a personal computer network; and a small stipend to compensate for participation in collaborative research. The experimental group consisted of six teachers of BASIC who taught nine classes (132 students) at five lab site high schools, the control group of nine teachers and 13 classes (239 students -- a pool large enough, it was hoped, to avoid the differences in ability that beset the preliminary study) at eight control sites. The classes were straightforward programming classes which met on average five times a week for 40 minute periods for an entire semester.

A general test of cognitive skills was administered as a pretest at the start of the term and readministered as a posttest at the end, when students' mastery of BASIC was also tested. At the time of the pretest students were asked to respond to a short questionnaire on previous experience with computers, computer programming, and BASIC or any computer language.

The first lessons presented a visual model of the computer that shows students what happens during execution of a program and helps them interpret what various BASIC commands do. The "paper computer," as it was called because students receive paper forms of the model on which they hand execute programs, helps counter some problems of fragile knowledge and strategic shortfall as well as strengthen students' knowledge of effects of commands. By imagining the computer's actions at a trouble spot, students who tend to give up easily can help themselves get moving and others can use the model to focus their activities and help them debug. These initial lessons provide students with a conceptual framework for understanding commands which involves thinking of a statement (command) in an analytical scheme of purpose, syntax, and action. It helps them to recognize, attend to, and organize important features of any new command and helps them write programs by asking them to consider the purpose, syntax, and action of commands they already know. Later lessons deal with strategies for thinking in "patterns," or multiple lines (chunk) of computer code that work together to accomplish a particular task.

Because the preliminary study had indicated that students needed additional instruction in planning and writing whole programs, the revised Metacourse provides a procedure that emphasizes planning, checking, and debugging, in addition to coding. As students proceed to higher level planning, they are encouraged to think of "interactions," a sequence of computer outputs and user inputs occurring as the user uses a program. For novice programmers, who frequently have difficulty moving from a given problem statement into initial stages of analyzing a task, this heuristic technique breaks programs into manageable "chunks" while emphasizing the planning needed to move from statement to coding. Students can then conceptualize sections of a program as patterns with specific purposes, as tools to create code above the level of a single command and extended into a repertoire portable across programs. With its reiteration of strategies for checking and debugging, the Metacourse tries to make it clear that bugs and debugging inevitably occur in producing a program and are not a reflection of poor programming.

Researchers conducted observations of all classrooms involved to record and rate (on the 7-point Likert scale) class dynamics, instructional style, and elements related to the Metacourse itself -- e.g., fidelity to the Metacourse, infusion of its concepts into the ordinary curriculum on BASIC, inclusion of bridges between programming and other academic or real-life situations. Teachers were found to use the Metacourse with fidelity, usually covering at least three-quarters of the material in each lesson and consistently referring to the principles of the Metacourse (paper computer; purpose, syntax, action; patterns). In contrast to their fidelity to the materials, they rarely pointed to bridges or applications to other academic areas or real-life situations. Students in both groups were responsive, attentive, engaged, and interactive with the teacher and in the non-Metacourse classes slightly more interactive with each other.

Findings

The final BASIC test, a standard paper-and-pencil programming test composed of 16 items, evaluated general programming skills -- hand execution, debugging, breaking a problem into subtasks -- as well as knowledge about programming. Results indicate that the experimental group gained significantly more than the control group -- about half a standard deviation -- in general competence in a variety of important programming skills. The magnitude of differences varied across subskills, which include using correct syntax to perform simple operations, tracing a program's actions through hand execution, and debugging and producing simple programs. Although transfer from the Metacourse to cognitive skills was not expected, some evidence of it was observed on the "repeats" and "decides" subtest, the one most similar to the programming tasks presented through the semester.

Researchers continued to meet with lab site programming teachers after the study ended to solicit their ideas on possible revisions of the Metacourse. Through these discussions the group identified and undertook three major sorts of revisions. First, they decided to change the format of the Metacourse from a series of lessons to a series of modules, in order to give teachers more choice and flexibility in adapting the materials to their existing courses. Some modules will help teachers introduce Metacourse concepts, others will help them infuse these concepts into other lessons, and still others will help them encourage transfer to academic areas beyond programming. Second, the revised Metacourse will enrich the mental model of the computer by including on-line versions of both the paper computer and the minimanual, a quick-reference guide to key BASIC commands. Third, the revised Metacourse will provide additional problem-solving heuristics to help students generate and debug programs.

Spring 1987 Study

Although major revisions to create the "second generation" Metacourse continued throughout the spring and summer, some minor revisions were completed in time to benefit the study undertaken in the spring semester of 1987.

These included expansion of the Metacourse to nine lessons and changes to make the materials more easily integrated into teachers' existing practice. The seven teachers in the spring study received considerably less support than those in the lab site study had. Although they had less direct contact with researchers, they received a complete Metacourse Manual before the semester began as well as a series of Metacourse Memos of suggestions and teaching tips from the research group and previous users of the Metacourse. This study was completed at the end of the school year, but the data analysis was delayed in order to finish development of the new modular materials before school opening in September 1987. Data analysis for the spring study was underway as Year Four ended.

Systems Thinking

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The field of system dynamics focuses on connections among the elements of a system and how the elements contribute to the whole. Based on the concept of change, it uses simulations -- simplified representations of a real-world system -- and computer-based mathematical models to represent complex relationships among variables in a particular environment. To build a system, the major variables it comprises must be understood; these can form a dynamic feedback system expressed mathematically as a set of simultaneous equations that can be shown to change over time and cause other variables and their interactions to change.

The Systems Thinking and Curriculum Innovation (STACI) Project, a two-year project begun in the academic year 1986–87, is a collaborative undertaking of the Brattleboro Union High School (BUHS), Brattleboro, Vermont, and the Educational Testing Service (ETS) with ETC to examine the cognitive demands and consequences of using systems thinking and simulation modeling software. The study tests the potentials and effects of using this approach to learning and instruction in secondary school curricula to teach both content-specific knowledge and problem solving skills, and examines the extent to which students acquire higher-order cognitive skills through interaction with a curriculum infused with systems thinking concepts and subsequently generalize knowledge and skills to other substantive areas.

Specifically, the study examined the effectiveness of *STELLA* (Structural Thinking Experimental Learning Laboratory with Animation, developed by B.

Richmond and P. Vescuso [1985] and available from High Performance Systems, Inc.) software, designed for the Macintosh™ microcomputer to teach systems thinking, content knowledge, and problem solving. By minimizing the mathematical and technical skills required -- the user supplies the logic and knowledge of a domain needed to build models, and *STELLA* creates the structural diagrams, graphs, and data that represent the system -- *STELLA* makes systems modeling approachable for the novice. It allows students to model the characteristics and interrelationships of complex systems in the real world and follow the evolution of the models over time. By altering characteristics of particular variables within the model, students can test the effects of changes on selected variables or on the system as a whole.

The Study

The study is being conducted at BUHS, which, since 1985, has been experimenting with several systems thinking activities, including a one-day seminar and a five-day workshop with experts from MIT and Dartmouth, to introduce the principles of systems thinking to teachers, students, parents, school board members, and the local public. These activities were initiated by a core group of four teachers trained to use the systems approach and integrate it into their courses. Systems thinking, taught by the four teachers interested in this approach, was incorporated into classes in general physical science, biology, and chemistry (for a total of 172 students); an equal number of traditional classes (181 students) taught by other members of the faculty were controls. Two substudies also were conducted: one involved a newly created seminar in which systems thinking was used to study historical events; the other examined the impact of introducing and implementing the systems thinking innovation on the school as an organization.

In this first year of the study several types of instruments -- existing, modified, or newly developed as needed -- were used to assess the research at various stages. Pretests, in-class tests, and posttests were used to assess ability, content-specific knowledge, and systems thinking and higher-order thinking skills (e.g., general problem solving, metacognition, self-regulation). Scores from the most recent standardized tests students had taken were supplied by BUHS, and the California Achievement Tests and a battery of ETS's own tests (including the Advanced Progressive Matrices) served as indexes of general ability. In addition, other measures were used to test skills hypothesized to underlie systems thinking: inductive and deductive reasoning, figural analogies, understanding relationships. ETS, in consultation with the BUHS teachers and systems experts, developed a 39-item instrument to assess knowledge of systems thinking skills along a continuum ranging from elementary concepts to complex modeling skills, focusing on such concepts as graphics, equations, variation and variables, causation and causality, feedback, looping constructs, modeling, and *STELLA*. This test was administered at the end of the year only to the systems thinking classes. In both the systems and traditional classes students were given modified versions of previous final examinations, to provide baseline assessments of

knowledge of the subject, and throughout the academic year teachers gave content-specific tests and exercises roughly comparable for both groups of classes and administered common final examinations.

Systems and traditional classes were observed by project members on six site visits when similar topics, such as reaction rates in the chemistry classes, were being covered. Interviews with the teachers provided additional information about the classes, particularly the systems teachers who were asked about issues confronted in implementing curriculum innovations and the effects on their teaching.

During the first year both instructional method and course content were exploratory. Some teachers were more successful than others in identifying appropriate applications for systems modules, and although all were interested in the possibilities offered by systems thinking and *STELLA*, all had to cope with the reality of heavy teaching responsibilities while working on developing an innovative curricular approach. In spite of the use of common texts as primary curricular components and the common final examinations, differences in emphasis, assignments, and classroom organization and style inevitably affected learning processes.

General Physical Science

The purpose of this course for ninth- and tenth-grade students is to introduce concepts of matter and energy that apply to everyday life as well as principles of measurement and concepts of work, energy, and motion. The systems thinking teacher supplemented the common text with other materials while the control teacher adhered to it more closely. Unlike colleagues using this approach in biology and chemistry, this teacher found difficulty developing causal loop structures in general physical science, where the topics did not lend themselves to simple feedback relationships.

Modeling, introduced at the start, provided much discussion through the year, with an emphasis on the general concept of models, an atomic model, models of electrical circuits to show distinctions and relationships among potential, current, and resistance, and a wave model to help students understand the structure of light. Mathematical models were introduced early, first in simple graphs (of distance, speed, and time) and then for understanding the concept of density.

After a brief introduction at the start of the year, *STELLA* reappeared in discussion of chemical bonding and the formation of compounds and again at the end for a class with motion detectors developed at the Technical Education Research Centers (TERC), Cambridge.

Biology

The common text for this course centers on the theme that living organisms share basic life processes -- food production, energy transfer, growth and development, maintenance and repair, and reproduction -- and the goal of the

course was to develop an understanding of those processes and their expression in a diversity of life forms. Methods and measures of scientific inquiry were presented, followed by the general principles of chemistry and cellular biology needed to comprehend physiological processes; the course included topics in genetics on heredity, reproduction, and variation and on evolution and the adaptations that promote survival.

The teachers agreed that this subject area most readily lent itself to a systems approach, emphasis on the concept of interrelationships offering great potential for identifying relevant examples. Systems thinking was introduced through definitions and principles (system, components of a system, feedback, causal relationships), the use of the "Modeling" videotape, and causal loops illustrated by biological examples (fight/flight responses, respiration, photosynthesis) and nonbiological examples (traffic dynamics and a spending-earnings-savings model drawn from *Introduction to Computer Simulation: A System Dynamic Modelling Approach* [N. Robert, D. Anderson, R. Deal, M. Garet, & W. Shaffer. Reading, MA: Addison-Wesley, 1983]).

Students initially appeared interested in learning concepts and discussing simple causal diagrams, but the complexities introduced led to some difficulties. Not all students could follow connections between loops, and the teacher found discussion of one loop at a time and a rule to guide students' pathway through the systems both helpful. The teacher reintroduced causal loops in a model for the role of enzymes in metabolism, using a problem-solving approach to interpret the process depicted to help students understand both metabolism and the idea of relatedness among cell structures. Although time did not permit the students hands-on experience with *STELLA*, graphing was used early in the second term to teach concepts of levels and rates in examples drawn from a population model and analogies to biological topics just reviewed (meiosis, meitosis). Students were later reintroduced to computer modeling with *STELLA* in laboratory work, when they could compare effects portrayed in the model and laboratory results, and near the end of the year they worked with computer modeling of oxygen production. Although their responses were generally positive, many indicated more hands-on experience with computers and *STELLA* was needed, and the teacher concurred.

Chemistry

The theme of this course was that characteristics of matter are dependent on their structure, and its goal was to develop an understanding of the properties of matter and their relationship to structure. It introduced concepts of moles, thermodynamics, and chemical equilibrium. In the introduction to basic terminology and concepts in systems thinking, the relationships of rates, time, and levels were illustrated by construction of formulas and graphing. Students were given word problems or data sets and instructed in graphing data, deriving rates and levels, and interpreting graphical trends, concepts then applied to construction of both causal diagrams and simple structural models in examples

drawn first from everyday life (the rate at which cars enter and leave a parking lot during a day), then from chemistry (smog, tooth decay).

In addition to the problems of time that beset all the teachers, the chemistry teacher discovered that modeling a chemical system involved a degree of complexity and knowledge often beyond students' understanding; the number and complexity of elements and chemical reactions made even an apparently simple model of tooth decay difficult. Development of accurate and appropriate examples for modeling was not easy. Topics in the core curriculum did not lend themselves to the integration of systems thinking, until, in the second semester, an appropriate application was found in reaction rates. The students, at first only moderately interested in the problems and in building models, grew more interested when *STELLA* was used to focus on this traditional topic, enabling them to see the relation between the systems thinking approach and the content and to develop a generic understanding of the behavior of an interacting set of variables.

Here, as in other science classes, models were combined with laboratory activities, i.e., created prior to experiments to introduce elements in particular reactions and to predict how the elements might affect each other, or created during or after an experiment to illustrate the behavior observed, simulate other conditions, and comment on predictions.

Substudy: War and Revolution Seminar

The War and Revolution seminar, conceived by the teacher and David Kreutzer of the System Dynamics Group at MIT, is unique in the prominence it gives to systems thinking. The study focused on historical events, with the intent of developing analytical skills and an appreciation of the complexities and importance of policy decisions. It was offered for the first time, to seven academically talented students (three of them National Merit Scholars), two of whom had received outside training in *STELLA* and had developed causal loop diagrams and structural models of other topics. These students assisted their classmates in learning to develop models and use *STELLA*. The class resembled a college seminar, meeting three times a week as a group and using the two remaining periods for individual work or in small cooperative groups. The primary text, *Thinking in Time* (R. Neustadt & E. May. New York: Free Press, 1986), was supplemented with sources on topics for group discussion and independent research, as well as major newspapers and news magazines, professional journals, books, government documents, and other media. The teacher used various revolutions (the Hungarian revolution of 1956 and the Iranian and Nicaraguan revolutions), along with Kreutzer's model of terrorism, to introduce systems thinking as a strategy for analyzing the dynamics of historical and current events. The students studied basic concepts for modeling systems, reviewed some existing models, and experimented with constructing their own.

Toward the end of the course the seminar participated in a special project on the problem of the Zimbardo Prison Experiment, a simulated prison

environment where college students assumed the roles of inmates and guards. Students were given one week to develop and prepare systems and *STELLA* models of the experiment and at the end handed in brief reports, causal models, and their *STELLA* models.

Substudy: Organizational Case Study

When new technologies and expertise are introduced into schools, changes occur in organizational structure, division of labor, patterns of communication, and distribution of authority and influence. These are being documented and analyzed for the impact of the introduction and implementation of systems thinking at BUHS. These elements were traced initially during two spring site visits through interviews with various people -- systems thinking teachers, faculty chairing the science and social studies departments, the principal, superintendent, and head of guidance, as well as other BUHS teachers. More interviews will take place in the second year, and the data will be synthesized into a case study depicting the evolution of systems thinking at BUHS and its impact on the school as an organization.

The first year of the STACI Project, a period of exploration rather than a formal test of acquisition and transfer, proceeded smoothly. The few implementation problems that occurred have been discussed in ETC Technical Report TR87-6 *The Systems Thinking and Innovation Project: Part I*: teachers needed more time than anticipated for curriculum development, and parental consent was difficult to obtain. These factors delayed data collection and limited the extent to which conclusions could be drawn from data. Obtaining parental consent will be undertaken as early as possible in the second year of the project.

On the other hand, teachers made considerable progress in developing curricula, and students generally responded positively to the instructional materials. One critical issue in curriculum development was the time required to develop expertise in systems thinking and then integrate it into existing curricula. Others were: (1) the sequence of knowledge appropriate to teaching systems thinking; (2) the best points in the curriculum to use with systems thinking; (3) development of examples that illustrate variables and relationships but are simple enough for students to understand; (4) introduction of *STELLA*; and (5) the effectiveness of systems thinking for particular concepts (i.e., is systems thinking worth the tradeoff in time that could be spent teaching the subject matter in more conventional ways?). The wealth of classroom data now available will enable preliminary comments on the impact of the curriculum innovation on teaching and learning, in particular data from the War and Revolution seminar about the effects of the systems thinking approach on knowledge acquisition.

On the basis of the first year's results, much effort will go into revisions of procedures for assessment, observation, and data collection. A delicate balance must be achieved between requesting information from teachers and burdening them with documentation. Several week-long observations in conjunction with

other procedures, it is hoped, will provide sufficient data from which to examine the impact of systems thinking.

RESEARCH IN NEW TECHNOLOGIES

Area Coordinator: Judah L. Schwartz, ETC

Part of ETC's mandate is to explore the educational uses of emerging technologies not yet widely available in schools but rich with educational potential. These projects have focused on the promise of the new technologies and attempted to foresee issues that will require attention as they enter the classroom and the curriculum. The Computer-based Conferencing Project continued to explore the potential of microcomputer-based conferencing systems to reduce isolation and promote collegial exchange among science teachers, while the Videodisc Project studied the potential of interactive videodisc technologies to enhance the teaching of scientific inquiry skills to junior high school students.

Computer-based Conferencing Project

Group Members:

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During the past two years this group has explored the potential of computer-based conferencing to support teachers in collegial exchange about their subject matter and their classroom practice. This medium has several unique capabilities: participants can read and write messages at whatever time is convenient for them; they can exchange both public and private messages; groups can interact even when participants are geographically separated; and messages are available to readers almost instantly. Because the medium had served for over a decade in mainframe computing to support a sense of professional community among geographically dispersed groups in business and academia, it was natural for ETC to consider whether conferencing could also support collegial exchange among teachers. The group hoped to address the isolation of science teachers, both from ongoing developments in science and science teaching and from their peers, a problem highlighted in recent national reports on science teaching.

Because no existing system seemed adequate for this purpose, ETC designed new conferencing software, *Common Ground*. In the first year of research, 70 volunteering secondary science teachers from eastern Massachusetts were

enrolled in a network with a number of guests and network facilitators, and the nature of exchanges and correlates of participation were examined. In public exchanges (37 percent of all messages), inquiries or replies on rather specific points predominated, with more extended exchanges on both specific and more general topics emerging occasionally. It was important to know whether the predominance of short, specific messages was temporary -- due to an initial shyness on teachers' part or to inexperience with the medium (as some other research suggested) -- or was a more enduring mode of collegial exchange. If teachers use networks mainly for access to diverse, specific information, then a large membership is indicated. If, on the other hand, collegial discussion is a network goal and will emerge only when teachers get to know each other, then perhaps a small membership is required.

This issue was addressed in the second year of research by comparing new and old members in a continuation of the Science Teachers' Network, by studying the interactions among teachers in a new network in which teachers had a common task and more face-to-face contact, and by analyzing discussions that occurred in each. The new network served the ETC Laboratory Sites Project -- 36 teachers and ETC staff who were implementing several ETC teaching innovations in five area schools. Network communication supplemented their monthly meetings. Through a donation from Apple Computer, each school received a computer and modem; teachers were trained in a preliminary meeting and during school visits. Midway through the year, members of one subgroup were given computers to use from home.

The data gathered for each network included the record of all public messages; a machine log of all message reading and writing; observations (from the host machine screen) of how members read and wrote while logged in; selected member interviews about general reactions as well as particular network discussions; and questionnaire data on machine access, computer experience, and previous acquaintanceship with other members.

In addition, the group reviewed the systems, social context, goals, and message printouts (in two cases) of four other networks whose goals included discussion among science teachers: Kimmel, Kerr, and O'Shea's conference on the mainframe EIES system for science teachers trying out new curriculum materials; McGraw-Hill's MIX mainframe network for subscribing science and other teachers throughout the country; and two networks developed by Bank Street College for science teaching activities.

Various analyses of new and old members' participation in the Science Teachers' Network showed the central importance of network topics -- not social comfort, experience with the medium, or degree of social facilitation by staff -- in motivating participation in public exchanges. Previous acquaintanceship increased writing overall. Among the science teachers, those with more network acquaintances wrote more private and public messages. The greater acquaintanceship and involvement in a common task of the lab sites members did not result in more public discussion than occurred among the science

teachers; on the contrary, only 15 percent of the the lab sites messages were public, compared with about 40 percent in both years of the Science Teachers' Network. Lab sites teachers engaged in general discussion and sharing of experiences at monthly group meetings, using the network mainly for private communication with their "advisors," teachers with past experience with the teaching innovations. As in other collegial networks, most writing was accounted for by a fraction of the membership. In both networks, despite their different purposes, about half of the members were inactive, while 25–35 percent were active or very active writers. Additional members participated mainly by reading. This variable use is attributable to technical/logistical factors such as convenient access to the computer and ease of use of hardware and software, as well as to personal comfort with the medium and interest in the topics of exchanges. Analyses of particular exchanges showed that discussions evolved according to ambiguities embedded in the topics and developed according to individual opinions and interpretations, even when the initial topic appeared to be relatively specific and concrete.

The science teachers construed the advantage of the network in terms of access to a variety of information and opinion, and they used it mainly in that way, with occasional more abstract discussions of larger issues. Similarly, the lab sites members used the network for particular information needs, mainly to communicate with advisers about their immediate concerns.

The results suggest that network planners should maximize the information-sharing potential of collegial networks, which may be a prequisite for discussion to emerge. At the same time, they caution planners against the view that simply providing a channel of communication in itself will promote public discussion among colleagues. It may be that specific topics are preferred by unacquainted members because it is harder to clarify meanings in computer-based communications than in face-to-face communication. The number and quickness of responses are unpredictable, and visual feedback is not available. There is, however, the opportunity to reach a large audience and to expand topics in multiple directions. Network planners need to consider both practical/logistical factors and the nature of information needed by the group. For a collegial exchange network to succeed, where members have only common interests and no common task, a large membership is recommended (perhaps ideally 100 regular users or 200 enrollees, and perhaps also guest experts) to insure that resources are available to meet the likely diverse, specific interests. Meeting information needs may be a prerequisite to the development of discussion. The larger and more active the network, the more important become means to organize information through system features or the help of moderators. For a network facilitating a particular task, planners should consider the fundamental communication needs of the task and whether they are compatible with features of the medium -- whether the task can benefit from diverse interpretations, immediacy, and group access, whether the topics can be adequately discussed through written exchanges, and whether variable response time will benefit or hinder the task.

Videodisc Project

Group Members:

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At the start of the Fourth Year the Videodisc Group's research focused on interpretation and organization of data collected during its initial study of the use in middle school classrooms of the prototype interactive videodisc *Seeing the Unseen*. The study was conducted to respond to three research questions:

(1) What did users like and dislike about the system?

(2) How was the system used? How did students and teachers respond to different modes of use?

(3) How did students interpret and understand the material presented?

The exploratory nature of the study afforded a wide range of rich and complex data to be sorted and understood, and the resulting report centered on themes of appeal, utilization, and comprehension (see ETC Technical Report TR87-4, *A Prototype science interactive videodisc: Research on in-school use*, April 1987).

Seeing the Unseen was used to explore five aspects of videodisc technology: (1) the importance of user control and interactivity; (2) the importance of high-quality visuals; (3) the potential of videodisc for promoting inquiry learning; (4) the effectiveness of individual, small-group, and whole-class instruction; and (5) the teacher's role with videodisc technology. Researchers observed students as they proceeded through the lessons, noting their strategies and difficulties, as well as their interactions with each other and with the teacher. The students found it easy -- and enjoyable -- to use the disc and appreciated the high level of participation and control it offered. They felt it combined the dramatic qualities of television with the self-pacing available with books and educational software, and they credited the visuals with contributing to the appeal of the technology. Teachers used the technology in a variety of ways; some let the videodisc lessons stand alone, others provided supplementary material, and still others used the disc as a tool in their own lessons. Most felt that the technology encouraged teachers to act as a guide or facilitator, even though many had difficulty actually assuming such a role.

Those results supported the potential of videodisc as a medium for science education and suggested strongly that it may hold particular promise for teaching concepts that are difficult to visualize by providing access to phenomena in remote locations or unobservable by the unaided eye, or by simulating experiments which require complex and expensive laboratory equipment.

The report concluded that future research should address (1) the fit between videodisc design and particular educational goals, (2) the role of the teacher and the amount and kind of training needed to prepare teachers for using this new technology, and (3) the most effective ways of integrating videodisc design presentations into instruction of individuals, small groups, and large groups.

Although their intention had been to produce a second videodisc, the group was led by these conclusions to focus in 1987-88 on two issues: (1) the applicability of different videodisc design approaches to classroom activities, and (2) the effect of school context on videodisc use. The group began to wonder about what happens as videodisc technology becomes available and teachers begin experimenting with its use in classrooms. What factors will influence how teachers and students integrate videodisc technology? How will teachers and students most effectively use videodisc in classrooms?

To learn more about the educational potential of videodisc technology and effective classroom use strategies, the group undertook an analytic study through the summer and fall, conducting and digesting research on ten areas in the design and use of educational videodiscs: (1) trends in the purchase and use of educational technologies; (2) the nature of the videodisc as an educational medium; (3) videodisc design models; (4) newer technologies (e.g., CD-ROM, DVI); (5) school culture; (6) teacher's role; (7) teaching and learning traditions; (8) effects of technology on teaching style; (9) issues related to the development of a School/Videodisc matrix; and (10) authority in the classroom (teacher versus technology).

Out of this research, the group is writing a paper to be completed in FY 88 which examines the nature of videodisc technology and educational design approaches and presents case studies of early educational experimentation with videodisc. The paper discusses how videodisc design in combination with school factors -- such as teaching and learning activities, access to equipment, and school culture -- affect how videodisc is used in classrooms. The paper suggests ways for secondary school teachers to take best advantage of what is uniquely useful about videodisc technology.

RESEARCH IN LABORATORY SITES

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During Year Four the laboratory sites project was conducted to demonstrate ETC's vision of teaching with technology and to learn what it takes to carry out this approach in regular secondary school classrooms. The project focused on three ETC-developed innovations: teaching with the *Geometric Supposer* to

incorporate inductive reasoning into the traditional geometry course, using Microcomputer-Based Laboratories equipment to teach students about heat and temperature, and infusing the programming Metacourse into introductory classes in BASIC.

To illustrate and study the implementation of ETC-developed examples of teaching with technology, the Center established laboratory sites in five Massachusetts secondary schools. The project supported and documented the process of implementing and extending these innovations under relatively realistic classroom conditions. The lab sites were designed to be something like the gardener's cold frame -- less protected than the hothouse environment of tightly structured research but more fully supported than most school settings. Throughout the year teachers in lab sites worked closely with members of the ETC work groups so that research and practice could inform each other. Research-based teaching innovations were translated into practical terms, while practical experience provided the basis for further research and development.

The Structure of the Project

The project was designed to take into account lessons from previous efforts to reform teaching practice through the introduction of new materials and approaches developed outside the school system. Briefly summarized, these lessons included: focus on the teacher as the primary character in classroom innovation; generate support from administrators; support an on-site facilitator; present a clear vision of the desired teaching innovation; follow initial training with continued assistance; build networks of innovators; sustain innovation through a community of reflective colleagues.

As much as possible, these principles guided the design and the process of establishing laboratory sites. ETC negotiated to establish laboratory sites at one high school in each of its four consortium-member school districts and with a Boston inner-city high school. In each case initial conversations were held with central office administrators and then with the building principal. These people identified appropriate personnel to introduce the laboratory concept first to department chairs, then to faculty. At each level of the school structure, people were invited but not required to participate.

The project sought to recruit at least two teachers for each of the three innovations at every laboratory site. This goal was compromised, however, when too few teachers taught appropriate courses or chose to volunteer for the project. An on-site liaison was recruited at each school to help coordinate the range of lab site activities and to serve as an observer of the project from the school's perspective. Selected by administrators at each site, the liaisons varied in position and kinds of experience. All were veteran staff members whose length and breadth of familiarity with their schools proved invaluable in negotiating the complex relations with ETC. The project also employed three advisors, one for each subject matter strand. These advisors, experienced teachers who were accustomed to teaching with technology, became members of the relevant ETC

research group. They met regularly with the teachers in lab sites, helping to plan lessons, adapting materials, observing classes, and consulting about teaching strategies. Their role was to help translate research results into terms feasible for the teachers. They also served as analogues of the on-site liaisons, helping to make and analyze the myriad negotiations necessary to link research with practice.

Lab site teachers met regularly with the members of the relevant ETC research group. Through discussions about the process and effects of carrying out the teaching innovation, these meetings helped teachers become clearer about the rationale behind the teaching materials and activities. By the same token, the researchers learned about the clarity, feasibility, and effects of their materials.

An electronic conferencing system was established, to supplement face-to-face contacts among lab site participants. Members of the ETC Computer-based Conferencing Project provided training and support in the use of the system and studied the nature of its use by lab site participants. Their research is summarized elsewhere in this document (see p. 44 of this report; see also ETC Technical Reports TR86-14 *Facilitating collegial exchange among science teachers: An experiment in computer-based conferencing*, January 1987, and TR87-12 *Talking about teaching, by writing: The use of computer-based conferencing for collegial exchange among teachers*, December 1987).

Research Design

The laboratory site project was designed primarily to learn what it takes to carry out ETC-developed innovations in regular schools. Each innovation exemplified an approach to teaching that ETC calls technology-enhanced guided inquiry. In this approach, the computer is used not as a replacement for the teacher but as a tool to enable teachers and students to gather and analyze data and to investigate problems. Although the primary focus of the project was implementation of ETC's innovations, it was hoped that the research would shed light on more general questions about the requirements for integrating technology-enhanced guided inquiry into the core curriculum and practice of schools.

The research was based on an interactive conception of the process of change in school practice. Some students of school change have focused on the adoption of new technologies; others on features of the implementation context, including the influence of key actors and of organizational values and structures. Acknowledging the interactive influence of all these elements in the change process, the project studied the innovations themselves, the teachers, and the school contexts within which lab sites operated.

A central concept in tracing the implementation process was the notion of mutual adaptation. We anticipated that the materials and strategies designed by the ETC research groups would be elaborated, extended, and adapted by lab site project participants. At the same time we expected that the curriculum and

classroom practice of lab site teachers would change as they incorporated these innovations into their classes. Our aim was to understand the aspects of the innovations and the lab site settings that necessitated and shaped these adaptations.

The research included two studies. One focused at the school level, yielding case studies of three lab sites tracing the process of the three strands of the project, clarifying what promoted and impeded their implementation with particular focus on relevant characteristics of the innovations and the school contexts. The second study focused on teachers involved in the geometry strand of the project. Its aim was to understand the ways teachers' knowledge, skills, and beliefs affected their use of the ETC-developed innovations and to clarify the kinds of experiences that enabled teachers to change their ideas and practices.

Multiple sources of data were monitored throughout the year. Lab site project researchers attended all meetings of the research groups with the lab site teachers and regularly visited lab sites throughout the year, observing selected lessons and interviewing teachers, liaisons, and other key actors. Advisors met regularly with the project leader and proved to be keen analysts of the many aspects of mutual adjustment necessary to increase the goodness of fit between innovations and lab sites. Field notes were made of these observations and interviews and some key meetings were tape recorded and transcribed. Coded and analyzed, these data formed the basis for an interim report prepared mid-year and circulated to all lab site participants. Participants were asked to review the interim report for accuracy of description and interpretation; their comments were taken into account in preparing the final project report.

The teacher study consisted of a series of interviews and observations with the geometry lab site teachers and advisor at the beginning, middle, and end of the academic year. In addition, she reviewed minutes from all meetings of the geometry group and notes prepared by the advisor after each on-site consultation with teachers.

Findings

The laboratory site project demonstrated that ETC-developed innovations could be carried out successfully in a range of school and classroom settings given the kinds of supports provided by this project. Although the degree of satisfaction expressed by teachers varied across sites and strands of the project, the majority believed the innovations had strengthened the educational experience offered to their students. With few exceptions, they expected to incorporate the innovations into their teaching in future years. Several geometry and programming teachers intended to introduce the innovations to their colleagues and to encourage broader use within their school systems. Detailed analyses of the impact of the programming and geometry innovations can be found in the reports prepared by the ETC working groups on those topics (see pp. 44 and 23 of this report; see also ETC Technical Report TR87-7 *An empirical study of a "Metacourse" to enhance the learning of BASIC*, September 1987 and TR88-6 *Guided inquiry and*

technology: A year-long study of students and teachers using the Geometric Supposer, January 1987; also TR88-1 *Teachers' thinking about students' thinking about geometry: The effects of new teaching tools*, forthcoming).

Focused as it was on the process, rather than impact, of implementing ETC-developed innovations, the lab site research indicated features of the innovations and the settings that shaped this process. Broadly speaking, the implementation requirements can be considered in two general categories: (1) the prerequisite conditions for introducing ETC-developed innovations in schools, and (2) the more subtle conditions shaping the integration of technology-enhanced guided inquiry into classroom curriculum and practice.

Introduction challenges

The prerequisite conditions are frequently underestimated by those whose primary interest is improving teaching and learning. Nevertheless, the lab site project confirmed what veteran computer-users know: gaining access to appropriate hardware, software, and related materials can be major barriers to effective use of computer technology in schools. The complex processes of acquiring necessary resources, locating and preparing space to house them in schools, and scheduling appropriate access to technology require coordination across various units of the participating organizations. The lab site project reduced these barriers in several ways. A substantial amount of hardware was donated to the project by Apple Computer, Inc., and supplied to schools which otherwise would not have been able to participate. Software was supplied by ETC and by Sunburst, Inc., publisher of the *Geometric Supposers*. Lab site liaisons and the advisors for each strand devoted long hours, extensive expertise, and collaborative devotion to the installation and maintenance of equipment. Teachers acknowledged that the technical assistance and moral support offered by these helpers was essential.

Integration challenges

Satisfying these prerequisite conditions, admittedly crucial and difficult, merely set the stage for a more subtle set of challenges. Incorporating technology-enhanced innovations into the classroom can be analyzed in terms of three features of classroom life -- curriculum, technology, teaching approach -- and two aspects of school context -- organizational goals and structures. Looking across three different innovations and five different school sites clarified some of the ways these aspects influenced the process of mutual adaptation between innovations and settings.

Curriculum

Two aspects of an innovation's relationship to the existing curriculum influence the ease with which the innovation can be carried out in the classroom. One is congruence -- the process is eased when the innovation directly addresses content and topics that the teacher customarily includes in a course. The other is

completeness -- an innovation is easier to implement when its features are spelled out in instrumental terms and supported by the teaching and learning materials necessary to conduct a class. While teachers often wish to adapt lesson plans, problem sets, and exercise guides, they are hard pressed to invent and produce such materials.

The programming Metacourse, which included detailed lesson plans, suggested scripts, teaching aids, student exercises, and learning aids, was specifically designed to address topics typically included in standard introductory programming courses. This effort to maximize the congruence and completeness of the innovative curriculum clearly facilitated the implementability of the Metacourse. To the degree that the other innovations fell short of this goal teachers found them more challenging.

Technology

A second dimension of comparison between the innovations and the settings concerned the technology and associated logistical demands. The more complex and unfamiliar the technology was, the more difficult it was for teachers to incorporate into their classes. The programming Metacourse employed relatively little new technology, since programming teachers and students were accustomed to working with computers. The science project employed computers, relatively elaborate and fragile peripheral devices, and an extensive collection of more traditional science laboratory supplies. While most science teachers and students were accustomed to some laboratory-based lessons, the technical and logistical demands of this innovation presented a significant challenge. The geometry innovation employed much simpler technology than the science lessons, but it constituted a serious hurdle for the geometry teachers not at all familiar with computers.

Teaching Approach

A third locus of discrepancy between the ETC innovations and existing practice is pedagogical approach. Lab site innovations were based on a teaching approach we call guided inquiry. This approach reflects an assumption that students do not learn difficult ideas simply by being told about them. Instead, they must actively change their minds, constructing knowledge through a process of revising and inventing ideas in light of new information and experiences. The teacher's role in this process includes presenting information, posing problems, guiding students' investigations, and helping students integrate their findings with the teacher's intellectual agenda.

Teachers in lab sites varied in the extent to which they usually incorporated a guided inquiry approach into their teaching. Most of the science and programming teachers were accustomed to running "labs" during which students investigated problems either by themselves or in small groups. Geometry teachers, in contrast, were most accustomed to teacher-directed lessons with the whole class. Dividing the class into small groups to investigate problems

constituted a major shift in practice for them. Geometry teachers needed more opportunities to think through how to accommodate these significant shifts in student and teacher roles, shifts that required some rethinking of responsibility, authority, management routines, and methods for assessing student work. Magdalene Lampert's research (ETC Technical Report TR88-1 *Teachers' thinking about students' thinking about geometry: The effects of new teaching tools*, forthcoming) focuses on the ways geometry teachers dealt with these challenges to their usual curriculum and practice.

Finally, organizational features of school systems exerted a powerful influence on the process of carrying out innovations in laboratory sites. Individual teachers varied in the extent to which their goals, preferred approach, and personal knowledge fit well with the ETC-developed innovations. But these individual variations were shaped and constrained by features of their school organization. Two key aspects of the school context concerned educational goals and the organizational structures and norms that controlled decisions regarding curriculum, assessment, and course assignment.

School system goals and self-image

When laboratory sites were viewed as subunits within a school that was itself part of a larger school system and community, the influence of broad educational goals became apparent. Faculty in one school consistently expressed confidence in their subject matter knowledge and their professional judgement. They expected many of their students to seek admission to demanding colleges and felt a responsibility to prepare them well to be continuing learners. In another school, faculty regularly commented that expectations for student and faculty performance were more modest because parents did not have high expectations for their students' academic achievement. At yet a third school, faculty talked more about the students' need for work on basic skills including prerequisite academic knowledge and fundamental attitudes and study skills that promote learning. While teachers within each of these settings varied in their goals and expectations, the school system's aims and self-image set a tone that supported or discouraged the implementation of ETC-developed innovations.

Organizational structures and norms

Expectations about teachers' professional responsibilities were mirrored (and no doubt shaped) by decision-making norms and structures in schools. Clarity and control regarding decisions about curriculum, course assignments, and assessment varied across sites. In one site curriculum requirements were set at the district level by a process over which lab site teachers felt very little control. At another site teachers seemed unaware of, or at least unconcerned about, school policies regarding curriculum. At a third school, all the teachers who taught a particular course formed a team which established the course syllabus , wrote the school-wide test, and met regularly throughout the year to review how the actual practice fit with these curriculum guidelines. These structures seemed to shape teachers' views about the autonomy they could exercise

in incorporating an innovation. Lab site teachers who participated in the process of setting curriculum and designing tests (or who were at least familiar with the process of making these decisions) tended to feel both a capability and a responsibility to negotiate an adjustment between their own practice and the lab site innovation.

In summary, research on the process of introducing ETC-developed innovations into laboratory sites clarified features of both the innovations themselves and the schools that influenced this process. Findings suggest that the implementability of research-based innovations is enhanced when they are directly related to the existing curriculum, presented in instrumental terms, and accompanied by classroom-ready materials. Changing curriculum and practice entails shifts in teachers' knowledge, skills, and beliefs which are shaped by features of the school context. Hence, the introduction of technology-enhanced guided exploration required not only extended support and assistance for teachers but also some negotiation of these contextual constraints. Amidst these complexities, the most encouraging result of the project was the evidence that teachers were eager to engage their students in more active participation in their own education. Given means and support to accomplish this goal, teachers were willing to make major efforts to reconsider their curriculum and revise their practices.

Additional reports on the laboratory site research include the ETC Topical Report TR87-9 *A model program in science, mathematics, and technology*, October 1987 and Technical Report TR88-3 *Collaborative research goes to school: guided inquiry with computers in the classroom*, January 1988. Related research conducted with partial support from the Office of Technology Assessment is reported in Technical Report TR87-10 *How technology affects teaching*, October 1987.

OTHER ACTIVITIES

AGENDA BUILDING AND REVIEW

This year, as in the past, ETC has carried out its responsibilities for agenda building and review on two levels. Within the Center, primary responsibility has continued to rest with the ETC Agenda Group and the Center's administrative staff, who work in consultation with the National Advisory Board and the ETC Industry Group. Together, these groups formulate the directions of the Center's work and coordinate its many activities throughout several organizations and school systems. In the summer, the Center developed a position paper which presents highlights of the findings of its research and describes future directions for research to capitalize on those findings. That paper will play an important part in ETC's dissemination efforts in Year Five.

Beyond the Center, ETC has created several avenues for impact on the broader national agenda for research in educational technologies. To consider

the long-term future of technology in the schools, the Center convened its 2020 Panel and, to contribute to current national educational policymaking, conducted a federally funded study of how technology is affecting teachers and how teachers would like to influence the future use of technology in schools.

Deliberations concerning Center-based Research

Agenda Group

The Agenda Group met approximately bimonthly in Year Four. This committee of the Center's administrative staff and representatives from each organization in the ETC consortium continued its role as a policymaking body, consulting with Project Leaders and Area Coordinators to set the Center's overall directions. It occupied itself particularly with analysis of cross-cutting themes emerging from the Center's work and with formulation of plans for Year Five, the final year of the Center's current contract with OERI. This year's Agenda Group members were:

Tony Cline, Educational Testing Service
Jack Green, Education Collaborative for Greater Boston
Kenneth Haskins, Harvard Graduate School of Education
Mary Maxwell Katz, ETC
Harry Lasker, Interactive Technology Systems
Daniel O'Connor, Watertown Public Schools, Watertown, Mass.
Augustus Pesce, Ware Public Schools, Ware, Mass.
Robert Peterkin, Cambridge Public Schools, Cambridge, Mass.
Judith O. Sandler, Education Collaborative for Greater Boston
Judah L. Schwartz, ETC
Kim Storey, WGBH Educational Foundation
John Strand, Newton Public Schools, Newton, Mass.
Charles Thompson, ETC
Martha Stone Wiske, ETC
Philip Zodhiates, Education Development Center

National Advisory Board

ETC's National Advisory Board continued in its consultative role, meeting formally in the fall of 1986. The members of this group included:

Patricia Davidson, University of Massachusetts, Boston
Charles A. Foster, Past President, Foundation for Teaching Economics
Barbara Jackson, William M. Trotter School, Boston, Mass.
Hernan LaFontaine, Hartford Public Schools
Anthony Oettinger, Harvard University
Judah L. Schwartz, ETC
Patricia Sturdivant, Houston Public Schools, Houston, Texas
Charles Thompson, ETC

Sr. Carolyn Walsh, Pope John XXIII High School, Everett, Mass.
Martha Stone Wiske, ETC
Brunetta Wolfman, Roxbury Community College

A New Co-Director

On June 1, Charles Thompson left his position as Co-Director of ETC to assume new duties as an Associate Dean at Michigan State University. Martha Stone Wiske, formerly Associate Director of ETC, assumed the co-directorship, and Mary Maxwell Katz, formerly Senior Research Coordinator of ETC, assumed the position of Associate Director.

Research Analysis Seminars

In the latter half of Year Four, as part of the process of planning and setting priorities for Year Five, the Center began a series of Research Analysis Seminars. Convened by Computing Area Coordinator David N. Perkins and Associate Director Mary Maxwell Katz, these sessions have involved all ETC senior administrators, area research coordinators, and research project leaders in the further distillation and clarification of the Center's findings and in the identification of appropriate audiences among educational researchers, policymakers, curriculum and software developers, and school practitioners.

Position paper

Agenda deliberations near the end of Year Four also focused on the development of the position paper, *Making Sense of the Future*, which summarizes the Center's findings to date and proposes directions for future research. In relation to an agenda for future research, the paper argues for investigation of the potential of an approach to curriculum development that falls between large-scale, whole-course efforts and narrowly targeted modules. The Center has labeled this intermediate path a "metacourse" approach, because its linchpin strategy is the design of groups of lessons of the sort exemplified by the ETC Programming Metacourse. These series of lessons, including necessary software and teaching materials, introduce important concepts, models, and strategies which can be incorporated into other lessons, thus infusing an entire course with an innovative approach. Co-Directors Judah L. Schwartz and Martha Stone Wiske drafted the paper -- originally in response to OERI's request for a summary document to serve as background material for the deliberations of its Study Group on Technology and Productivity -- and then revised it in response to feedback from ETC senior researchers and others at the Center. Revisions continue, and in early 1988 the paper will be published in booklet form and used extensively in the Center's Year Five dissemination activities.

Deliberations concerning the National Research Agenda

2020 Panel

In the spring and summer of Year Three, ETC laid the groundwork for the deliberations of its 2020 Panel, which convened to consider the role of educational technology in the early part of the twenty-first century. The panel was organized in the hope that its observations and recommendations would contribute to a broad national agenda for research in educational technologies. On October 15-17, 1986, the 14-member group met in Manchester, Vermont, for three days of face-to-face discussions of papers the participants had written and exchanged prior to the meetings. The group's task was to imagine a desirable state of affairs for education and technology and to identify what it would take to make that vision a reality.

Following the October meetings, the panel moved into the next phase of its work, which was to revise their papers in light of those discussions. Revisions continued through the winter so that by the spring manuscripts were ready to submit to Lawrence E. Erlbaum, which has agreed to publish the papers as a book. Chairperson Ray Nickerson drafted an overview chapter and served as coeditor of the book with Philip Zodhiates, the staff person for the panel. The book will include a preface by Judah L. Schwartz and Charles Thompson and a foreword by Zodhiates. An executive summary of approximately 20 pages in length will be published separately. Both are expected to be released in the fall of 1988.

In addition to the overview chapter by Nickerson, the book will include:

William Bossert: The Use of Technology to Improve Two Key Classroom Relationships

David Cohen: Educational Technology and School Organization

Stephen Diaz: Educational Change and Educational Technology

Andrea diSessa: What Will It Mean to Be Educated in 2020?

Wallace Feurzeig: Discipline-oriented Learning Technology

Howard Gardner: Mobilizing Resources for Individual-centered Education

Thomas K. Landauer: Education in a World of Omnipotent and Omnicient Technology

Shirley M. Malcom: Technology in 2020: Educating a Diverse Population

James Minstrell: Teachers' Assistants: What Could Technology Make Feasible?

Roy Pea: The Knowledge Transfer Problem

Lauren Resnick and Ann Johnson: Learning Theory as a Guide to Educational Software Development

Alan Schoenfeld: Mathematics, Technology, and Higher-order Thinking Skills in the Near and Not-so-near Future

Elliot Soloway: Computer Science Education at the Precollege Level: A Research Plan

A Study for the Office of Technology Assessment

In the spring of Year Four, ETC was invited by the Office of Technology Assessment (OTA) to submit a proposal for funding to conduct a national study of the effect of technology on teachers and teachers' effect on technology. The study was part of a larger OTA effort to gather information for use by the U.S. Congress in setting priorities for national legislation and funding for educational technology. The Center saw it as an opportunity to contribute to the national agenda for research and policy concerning computer use in schools. Because the purpose of the OTA study coincided with plans already made in conjunction with Education Development Center to conduct a related Special Study, the Center applied for the OTA funding and proposed to combine it with OERI monies previously set aside for the Special Study.

In June, ETC was awarded the OTA contract to conduct telephone interviews with 80 elementary and secondary teachers in ten sites around the country to find out, for example, what kind of hardware and software their systems have, how they use computers for teaching or school-related activities, what kind of training and support they receive or would like to receive, how decisions are made in their districts, and how computers are affecting them and their students. Data were collected and analyzed during the summer, and the final report was submitted to OTA and OERI in late September.

The project's technical report contains seven composite profiles of teachers, each representing a cluster of those interviewed. The profiles portray a spectrum from those who are nonusers or ambivalent occasional users of technology to those who use computers daily to teach computer literacy or who are integrating technology into the teaching of mathematics, science, and other subject matters. Asked how computers have affected their teaching, many teachers reported that the technology had helped them move away from the traditional whole-class, chalk-and-talk method of teaching. With computers students work more on their own or in small groups, while the teacher circulates among them as facilitator, consultant, and coach. Though it requires them to make some difficult role adjustments and invent some new classroom management strategies, most teachers describe this change as positive and invigorating.

Researchers also asked participants what resources and supports would help them use computers more effectively. Most felt that access both in the classroom and in computer labs would be ideal. They considered good training and follow-up assistance essential, and the most satisfied teachers seemed to benefit from layers of support: on-site aids to assist with logistics, a district computer coordinator to help them stay abreast of hardware and software developments, colleagues with whom to share successes and failures, a supportive building principal, and clear district-level priorities.

The findings from this study suggest that computers share at least one characteristic with other significant technologies: using them effectively in schools requires an integrated system of resources. Specifically, there must be: adequate hardware, appropriate software, related courseware, a knowledgeable

and skilled teacher, reasonable mechanisms for assessing teaching and learning, technical assistance, and a supportive environment for teachers' professional growth and development.

DISSEMINATION

Dissemination of the results of the Center's work has continued to occur through several channels. As our work has matured the number and quality of our disseminable products has expanded accordingly.

Newsletter

ETC's national newsletter, *Targets*, was published three times in Year Four, in the fall, winter, and spring. Each issue featured brief summaries of the Center's work and contained a product list and order form for all ETC products available to the public. *Targets* is distributed to over 14,000 people and institutions throughout the United States and in many foreign countries.

Technical Reports

ETC published ten technical reports during Year Four, which added to the existing list of reports available by mail or in person from the Center. These included not only reports from the Center's research groups in subject matter areas, but reports on special projects such as the study for the Office of Technology Assessment (see p. 60 of this report) and the model science and mathematics program at the Burke School in Boston (see ETC Topical Paper TP87-9 *A model program in science, mathematics, and technology*, October 1987). Though intended primarily for researchers, many of these reports discuss the classroom implications of the work and thus are of interest to school people as well. This year, the Center filled 1,515 requests for technical reports, many from school districts who learned of the materials through *Targets*.

Videotapes

In the fall of 1986, ETC, in conjunction with Education Development Center, completed production of a videotape entitled *Image, graph, symbol: Representation and invention in the learning of mathematics* and began making it available for distribution. This 28-minute tape makes the case for multiple representations in mathematics education, suggesting that when students have the opportunity to work with concrete as well as abstract representations and to move at will among a variety of representations, their understanding of and facility with mathematical ideas improves.

Image, graph, symbol demonstrates the use of multiple representations in a variety of classroom settings: a seventh-grade class uses geoboards to learn about the Pythagorean Theorem; fifth and sixth graders try out an experimental computer program designed at ETC to help students improve their proportional

reasoning; an eighth-grade teacher with only a single computer at her disposal uses the program *Green Globs* to review with her students the relationship between graphs and equations; high school students working with the program *Guess My Rule* learn to derive equations from tabular and visual data; another high school class uses the *Geometric Supposer* to investigate the properties of and make conjectures about similar triangles. The videotape also includes interviews with two mathematics educators -- Judah L. Schwartz, of the Massachusetts Institute of Technology and Co-Director of ETC, and Robert Davis, of the University of Illinois.

Throughout the year ETC has also continued to disseminate an earlier videotape: *New tools for learning: Using computers in science education.* This 27-minute tape presents five uses of computers -- tutorials, drill and practice, simulations and games, measurement and data analysis, and programming -- and discusses the effectiveness of each one for teaching different kinds of scientific knowledge. Both tapes are available in 1/2-inch or 3/4-inch format and are appropriate for audiences of parents, teachers, or school administrators. In all, 165 copies of these two tapes were sold in Year Four.

During the spring, ETC and EDC began to shape ideas for a third videotape which will illustrate teaching with ETC's guided inquiry approach and will both demonstrate and discuss such important teacher skills as posing problems, guiding student inquiry, and helping students to integrate and consolidate the results of their inquiry.

Software

ETC added no new pieces of software to its product list this year but continued to make available *Common Ground* and *Immigrant*. *Common Ground* is microcomputer-based teleconferencing software, created by ETC project associate Chris Hancock and used by the Center's Computer-based Conferencing Research Group. Available with complete documentation for IBM and DEC microcomputers, it provides for enrolled participation, private messages, and public discussions for up to 100 members at a time. *Immigrant* is an experimental curriculum designed by the ETC Applications Group to recreate the experience of Irish immigrants in Boston from 1840 to 1860. The integrated software package includes: Appleworks™ data files with lists of passengers, jobs, and housing; spreadsheet templates that allow students to calculate food, clothing, and household expenses; and a wordprocessor. Also included is a teaching guide for a simulation in which students follow a particular immigrant family's experience. In Year Four, ETC sold 819 copies of these two software packages.

Other Dissemination Channels

ETC continues to submit monthly research abstracts for posting on *Edline*, an electronic bulletin board providing information on research in progress at various research centers around the country.

TRAINING

ETC also communicates the results of its work through its sponsorship or cosponsorship of a variety of seminars and conferences and through the teaching activities of the Co-Directors. These events present the results of the Center's own work and create a forum for broader discussion of technology and education.

Conferences

This year ETC cosponsored two conferences, each with three other Cambridge-based organizations doing work in technology and education: Lesley College; Bolt, Beranek, and Newman, Inc.; and Technical Education Research Centers.

The first conference, the NINTH ANNUAL COMPUTER CONFERENCE, which began on April 30, was a three-day event on current and future roles for technology in the schools. One hundred fifty teachers, computer specialists, and school administrators from across New England participated. Ray Nickerson of Bolt, Beranek, and Newman, who chairs ETC's 2020 Panel, gave the opening address, "Educational Technology in 2020: The Possible and the Desirable."

On Friday, May 1, ETC associates participated in two panel discussions. The first, "How Schools Change: Is Technology Different?" was moderated by Charles Thompson; Martha Stone Wiske of ETC and David Cohen of Michigan State University were panelists, and Linda Roberts of the U.S. Office of Technology Assessment was a respondent. The second panel, "How Much Instructional Responsibility Will Computers Have in 2020?" was moderated by Judah L. Schwartz, with John Richards and Elliot Soloway of Yale University as panelists. That afternoon the sponsoring organizations each hosted an open house to display their most recent innovations. ETC featured interactive videodisc demonstrations by Judah L. Schwartz, Laurie Pattison-Gordon, Carol Chomsky, and Matthew Hodges.

On Saturday, May 2, Adeline Naiman's keynote address on "Science, Technology, and Fate Control" was followed by a smorgasbord of more than thirty presentations on classroom applications of information technologies. ETC presenters included Steven Schwartz and Kathy Hollowell of the Programming Group, Cornelia Tierney of the Fractions Group, and Carol Smith and Lorraine Grosslight of the Weight and Density Group.

The second conference, the TECHNOLOGY IN THE CLASSROOM WORKSHOP, was a five-day symposium to disseminate the work of each of the sponsoring institutions in pre-college mathematics and science. More than 150 elementary

and secondary school teachers, university professors, and school administrators from all over the United States attended the program of full-day workshops. Two ETC research projects offered workshops: Steven Schwartz and Kathy Hollowell of the Programming Group presented "The Development of a "Metacourse," and Myles Gordon and Richard Houde of the Geometry Group presented "Guided Inquiry in Geometry: Teaching with the *Geometric Supposer*."

In addition, ETC provided training to participants in the Laboratory Sites Project, in part through two all-day conferences held in December and June. Held at Harvard, the conference in December reunited lab site participants for the first time since their meeting the previous summer, giving them an opportunity to learn about other elements of the project, gain perspective on their particular part, and celebrate the progress made. The morning was given over to discussion of guided exploration, in which the teaching approaches in the three innovations were compared to discern commonalities and distinctions. Participants viewed a videotape of a class taught with the *Geometric Supposer* and, with that as an anchor, discussed and clarified elements of this pedagogical approach and the roles of teachers within it. Later in the morning, members of the electronic conferencing project provided further information, training, and encouragement for the role of the conference in the lab sites project. In the afternoon, the Geometry, Science, Programming, and Liaisons groups each met for regular monthly meetings. The conference permitted a valuable opportunity for uninterrupted reflection on the project's goals, progress, and plans.

To end the year, ETC held a conference for lab site participants at the Harvard Faculty Club, which began with reports from each project. Teachers described the impact of the innovations on themselves, their courses, and their students, and the Liaisons recounted hardships and solutions in coordinating the projects. The discussion touched on tensions and benefits of collaborative research for both university-based researches and school teachers. In spite of the demands the year had made on them, the teachers were overwhelmingly encouraging in their responses.

Seminars

In Year Four ETC continued its tradition of providing training through a regular seminar series. These gatherings served, through presentations by the Center's own researchers, to convey and extend the findings of ETC research and, through presentations by invited guests, to explore related issues associated with educational technology. This year's seminars included:

"Promoting Conceptual Change through Computer Modeling: How Sixth Graders Learned about Weight, Density, and Matter," Carol Smith, ETC

"Astronomy from the Ground Up," Philip Sadler, Smithsonian Astrophysical Observatory

"Guided Inquiry and Technology: A Year-Long Study of Children and Teachers Using the *Geometric Supposer*, Dan Chazan, ETC and EDC; Myles Gordon, EDC, and Richard Houde, Weston Public Schools

"Explaining Kids' Explanations" by Dalton Miller-Jones and Joseph Becker, City University of New York

"Using Databases to Expand Cognitive Schema," Virginia Larabee, Castleton State College, Vermont

"Sharing Knowledge through Computer Networking: The Story of the ETC Science Teachers' Network," Eileen McSwiney, Education Collaborative for Greater Boston; Mary Maxwell Katz, ETC; and Kathryn Stroud, ETC

"The Thinkertools Project: Enabling Middle School Students to Induce Newton's Laws," Barbara White and Paul Horowitz, Bolt, Beranek, & Newman, Inc.

"What Middle School Students Do, Can, and Should Know about the Nature of Science," Susan Carey, Massachusetts Institute of Technology and ETC

"The Algebraic Proposer: A Computer Environment for Modeling and Problem-Solving," Judah L. Schwartz, Massachusetts Institute of Technology and ETC

"Computer Tools for Statistical Reasoning," Andee Rubin, Bolt, Beranek, & Newman, Inc.

"Building the Cognitive Foundations of Proportional Reasoning Using "Multiple Representation Software," James Kaput, Southeastern Massachusetts University and ETC

"The Value of Formative Research in the Design of Children's Television in Mathematics and Science," Milton Chen, Harvard Graduate School of Education

"Real World Constraints on Educational Software Development," Glenn Kleiman, Education Development Center

Courses

Both Co-Directors of ETC are members of the faculty of the Harvard Graduate School of Education, where they offer courses on topics related to the Center's work. This year, Charles Thompson again offered a course on "The Computer as an Innovation," which dealt with the complexities of integrating computers into schools. Judah L. Schwartz offered a course on "Educational Software Design," which he cotaught with Robert Tinker of Technical Education Research Centers, who was a member of the ETC Heat/Temperature Research Group and an ETC Visitor during the fall semester of 1986. Schwartz and Tinker also cotaught a course entitled "On Learning to Build Scientific and Mathematical Theories," in which students explored microcomputer environments that provide rich opportunities to analyze data and to generate and test hypotheses in both mathematical and scientific domains. Tinker also offered a course on Microcomputer-Based Laboratories which argued for a highly phenomenological approach to science instruction and presented hardware and software designed to implement this approach. All these courses extend and enrich the ideas and approaches used in ETC research projects. A similar kind of communication and strengthening of ETC research is accomplished through courses taught by Center researchers who are members of the faculties of other universities.

Presentations

On more than fifty occasions this year, the ETC co-directors, other central staff members, and research group members represented the Center by participating in conferences and delivering speeches. Among the organizations to which they made presentations were the American Educational Research Association, the Group for Psychology of Mathematics Education, the Council of Great City Schools, the Soviet Academy of Sciences, the School Mathematics and Science Association, the North Central Regional Educational Laboratory, and the National Council of Teachers of Mathematics. They also spoke to audiences at Illinois State University, the University of Georgia, Boston College, City University of New York, Syracuse University, the University of Guelph, the University of Bielefeld, Germany, and Cornell University.